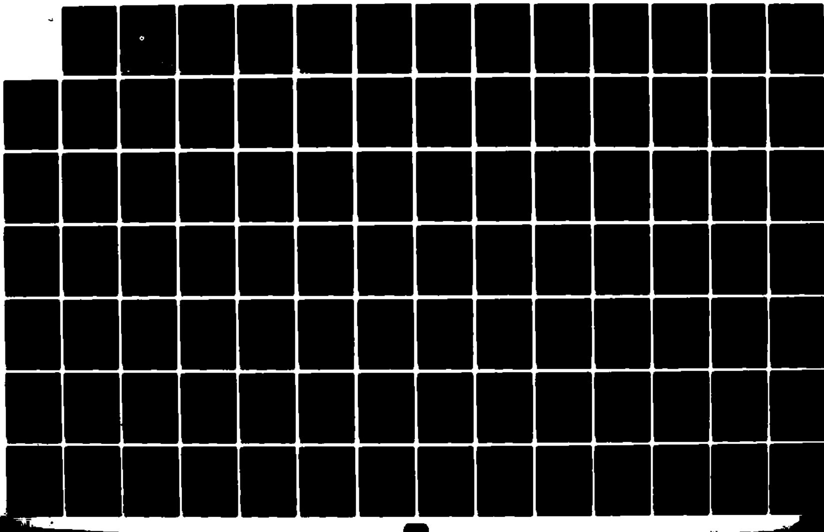
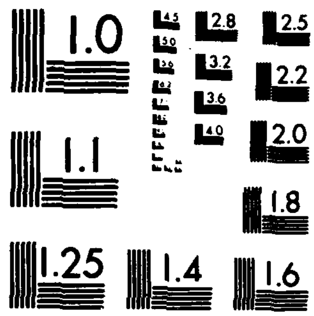
AD-A138 947 PRELIMINARY ANALYSIS OF AUTOMATIC MORSE CODE TRANSCRIBERS FOR USE IN US C..(U) SPEECH COMMUNICATIONS RESEARCH LAB LOS ANGELES CA E W MERRIAM 1984 1/2

UNCLASSIFIED USCG-D-38-83 MDA904-82-C-0415 F/G 17/2.1 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

(10)

Report No. CG-D-38-83

Preliminary Analysis of Automatic Morse Code Transcribers For Use In U.S. Coast Guard Operations

January 1984

This document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161

Final Report

Prepared for:

U.S. Department of Transportation
United States Coast Guard

Office of Research and Development
Washington, D.C. 20593

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

The contents of this report do not necessarily reflect the official view or policy of the Coast Guard; and they do not constitute a standard, specification, or regulation.

This report, or portions thereof may not be used for advertising or sales promotion purposes. Citation of trade names and manufacturers does not constitute endorsement or approval of such products.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
CG-D-38-83	AD-A138947	

4. Title and Subtitle	5. Report Date
Preliminary Analysis of Automatic Morse Code Transcribers for Use in Coast Guard Operations	January, 1984
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
E. William Merriam	
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
FEL Industries 200 Wakelee Road P.O. Box 200 East Dover, VT 05341	11. Contract or Grant No. MDA904-82-C-0415
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Department of Transportation United States Coast Guard Office of Research and Development Washington, D.C. 20593	Final Report
	14. Sponsoring Agency Code G-DMT-3

15. Supplementary Notes

16. Abstract

This report discusses the possible use of automated Morse code transcription techniques for U.S. Coast Guard operations. The primary purpose of such use would be in the automation of routine Morse code receiving tasks.

Coast Guard operations are analyzed to review day-to-day procedures, determine the type of Morse code information received, the quality and speed range of received code, traffic loads, experience level of Coast Guard operators, and other factors that may influence the usefulness of an automated transcription system. The technical aspects of the received signals are also reviewed as to strength of signals, fading, bandwidth, frequency range, quality, etc.

Tentative essential and desirable requirements are established for an automated system, and some criteria are established for determining the usefulness for such a system.

Fifteen commercially available transcribers and the techniques of three research projects are reviewed. While all of these contribute useful techniques, it is found that none is adequate to support the Coast Guard requirements. However, a combination of these and other techniques hold promise if a development effort is undertaken.

An integrated design is presented that contains components to do receiver tuning, signal processing and separation, code transcription, word matching, syntactic, semantic and pragmatic interpretation. All of these are mediated by a control component which will allow for the great variety of situations that arise in the Coast Guard Morse environment. Finally, components to allow operator intervention, analysis, and logging are described.

17. Key Words	18. Distribution Statement
automatic Morse code transcription automated communication systems automated CW transcription radio operator CW operator	Document is available to the United States public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	96	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

METRIC CONVERSION FACTORS

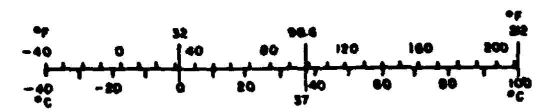
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



...ion For
...RA&I
...B
...nced
...cation
...tion/
...bility Codes
Dist
Avail and/or Special
A-1

Coast Guard Morse Transcription - Preliminary Analysis
FEL Industries - January 1984

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

The work reported here was supported by the United States Coast Guard Office of Research and Development. The continuing interest and friendly help of Mr. Dean Scribner of that office has enabled this project to address some of the most significant issues in automatic Morse code understanding.

Additionally, an active dialog with Lt. Ed Brady, CO Boston Comsta helped immeasurably to keep this project relevant to the real-world Coast Guard missions. Operations tours given by Commander Bob Philpott, when he was CO, Boston Comsta and RMC Paul Eginrider also of Boston Comsta, provided much of the observations regarding station operators.

Chris Kayes of FEL Industries programmed the micro-computer interface that allowed us to run transcription tests with actual Coast Guard Morse code signals and he was assisted by Sam Merriam in the debugging of that interface. Micki Gang, also of FEL Industries performed a variety of administrative tasks, including editing and proofreading the reports.

Finally, acknowledgement is made to Dr. John Makhoul of Bolt Beranek and Newman, Inc. for providing invaluable information and insights into the Linear Prediction signal processing method.

Coast Guard Morse Transcription - Preliminary Analysis
FEL Industries - January 1984

ABSTRACT

This report discusses the possible use of automated Morse code transcription techniques for U.S. Coast Guard operations. The primary purpose of such use would be in the automation of routine Morse code receiving tasks.

Coast Guard operations are analyzed to review day-to-day procedures, determine the type of Morse code information received, the quality and speed range of received code, traffic loads, experience level of Coast Guard operators, and other factors that may influence the usefulness of an automated transcription system. The technical aspects of the received signals are also reviewed as to strength of signals, fading, bandwidth, frequency range, quality, etc.

Tentative essential and desirable requirements are established for an automated system, and some criteria are established for determining the usefulness for such a system.

Fifteen commercially available transcribers and the techniques of three research projects are reviewed. While all of these contribute useful techniques, it is found that none is adequate to support the Coast Guard requirements. However, a combination of these and other techniques hold promise if a development effort is undertaken.

An integrated design is presented that contains components to do receiver tuning, signal processing and separation, code transcription, word matching, syntactic, semantic and pragmatic interpretation. All of these are mediated by a control component which will allow for the great variety of situations that arise in the Coast Guard Morse environment. Finally, components to allow operator intervention, analysis, and logging are described.

Coast Guard Morse Transcription - Preliminary Analysis
FEL Industries - January 1984

EXECUTIVE SUMMARY

This report discusses the possible use of automatic Morse code transcription techniques for U.S. Coast Guard operations. The primary purpose of such use would be in the automation of routine Morse code receiving tasks, in an effort to reduce personnel requirements. While taking a cursory look at personnel levels and training costs, the bulk of the report deals with the operational and technical aspects of the problem, under the theory that if a transcription system is not feasible, then cost considerations are irrelevant; and if it is feasible, a more detailed cost/benefit analysis will be required anyway. The project has been broken down into the following areas:

1. Analysis of Coast Guard Morse code operations
2. Analysis of the technical aspects of received Morse code signals
3. Evaluation of both of the above to determine the requirements of a transcription system that will meet the Coast Guard's needs.
4. Evaluation of existing transcribers and existing and potential transcription techniques.
5. Recommendation of transcription techniques to be used by the Coast Guard.

Coast Guard Morse Code Operations:

The analysis of current Coast Guard Morse code operations was accomplished by:

1. Visiting a Coast Guard Communications Station
2. Reviewing various Coast Guard documents
3. Discussions with Coast Guard personnel
4. Analysis of audio tapes of Morse code signals received on Coast Guard frequencies as well as the corresponding logs.

A Coast Guard Communications Station may have one or more operating positions where signals are listened for on a specified frequency. If the signals are meant for the listening station, the

operator responds to them. In all cases, the signals are logged. The information contained in the signals varies in content from ordinary English sentences to coded groups of numbers, with most communication being carried out in an abbreviated jargon used by radio operators for speed and efficiency.

The overall quality of the received Morse code is not good since sending operators exhibit very sloppy habits which result in code that is difficult to read and which contains uncorrected errors. The eed normally varies from 15 to 25 words per minute, but excursions o side this range are not uncommon, and the speed may change even withi single transmission. The ability of the Coast Guard operators t understand this code also varies widely, with the average operator capable of receiving 18 words per minute. It was observed that operators would experience difficulty with a signal and yet still make a complete log entry for it. Upon analysis of the log and an audio tape corresponding to that log, cases were found where the log entry had no relationship to the information contained in the signal.

The number of stations using a particular channel varies from none at all for long periods of time to many all at once. Unfortunately, no data is available on the amount of received Morse code traffic, but it is expected to decline over time. It does not appear, however, that it will become extinct in the near future.

There are 20 to 25 land-based positions and 60 to 70 ship-based ones that are capable of Morse code operations. Somewhat less than this number would be in operation at any one time. If the land-based positions were replaced with automatic transcription equipment, the

personnel cost savings would be approximately $1,480,000 per year. In all likelihood, no direct savings would result from replacing the ship-board units since other duties are performed by the Morse operator.

Technical Aspects of Received Signals:

Tape recordings and live signals from the 500 kHz and 8364 kHz channels were analyzed in order to determine parameters that could affect the design of a Morse code transcriber. These signals vary from the very weakest to those that are strong enough to overload the receiver. Due to changes in conditions, these can change in strength gradually over several minutes or rapidly within the space of only a few Morse characters. The bandwidth of the signal itself is approximately 300 Hz and the audio frequencies produced at the receiver output range from 100 to 5000 Hz. Several cases of rapid frequency shift (chirp) were observed, and operators reported that occasionally signals occur which sound raspy or which contain loud clicks.

Tentative Requirements for a Morse Transcriber:

It is tempting to say that in order for a transcriber to be useful, it must do as well as a human can do, but as pointed out earlier, it is not known how well (or poorly) humans really do. Furthermore, do we choose the best human's performance; the worst, or one in between?

From a practical point of view, a useful transcriber must be able to deal with all of the various types of signals: too strong or too

weak ones, fading signals, ones with chirp, buzz, or clicks, and ones which are keyed by poor operators. In addition, it must be able to deal with multiple interfering signals and atmospheric noise. It must be able to handle them in a manner that will allow it to accurately transcribe a large percentage of the desired messages (say 90%) without assistance of any kind. (It is doubtful that there are many human operators who can consistently achieve this rate.) If a transcriber is able to do this, then the Morse code operation becomes very similar to that of radio teletype, where the operator does not know the transmitted code but does know the various radio communication procedures.

Commercially Available Transcribers:

When this project started, it was believed that the goals of the commercially available transcribers were similar to the goals of this project and that it might be possible to find one that would come close to meeting the technical and operational requirements of the Coast Guard. After reviewing fifteen such units, it is now evident that the goals are not the same in that they are oriented toward being able to decode machine-sent signals and/or to being a training aid, primarily in the amateur "Ham" radio environment. Because of this, the transcription techniques used are all based on the notion that explicit thresholds (dividing lines) exist which can separate the marks and spaces into distinct categories. Except for machine-sent and very well hand-sent code, this assumption is simply not valid, as shown by the histograms of raw data in Appendix B.

Coast Guard Morse Transcription - Preliminary Analysis
FEL Industries - January 1984

Of the two methods used to extract the Morse timing data from the audio signal, the envelope-detection technique proved unusable except under the best signal conditions. The other technique (the use of a phase-locked loop, which indicates a mark when an audio tone is close to a specific frequency), produces better results, but suffers because it requires precise receiver tuning by the operator. However, an adaptation of the technique which may be viable is presented later.

Therefore, our conclusion is that none of the commercially available transcription devices are appropriate for use in the Coast Guard Morse code environment and only one of the techniques used in them (phase-locked loop demodulation) has promise for applicability to the problem.

Experimental Research Projects

Experimental research projects are reported on which have taken place at the Naval Postgraduate School, Massachusetts of Technology, and FEL Industries. All three projects have used the notion of confidence values or probabilities. The Naval Postgraduate School work shows how these probabilities can be obtained and how they can be combined into a cumulative probability model of the signal processing and transcription process. While the work shows that such a model is possible in theory, it points out that in practice building such a model is very difficult and that much of it will need to be constructed on-line for each separate Morse operator using a variety of non-probabilistic "world knowledge".

The MIT work attempts to use such world knowledge by employing the concept of "run-length sequences" (a representation of a word by

the Morse code marks that comprise it, leaving out any space information) and a limited grammar of the English language. Both of these techniques have applicability in an eventual transcriber design.

The FEL Industries project consisted of establishing a Morse operating position, complete with various analysis tools, in such a way that a variety of techniques could be tested. Results were obtained for the envelope detection and phase-locked loop signal processing techniques that are similar to those described earlier for the commercially available transcribers. The phase-locked loop concept was elaborated upon and found that the precise tuning problem could be eliminated. In addition, a transcription technique was developed that abandons the notion of mark-space thresholds and instead uses a notion of floating probability distributions which incorporates both a short- and long-term component into the model of the sending operator. This technique was found to produce results better than any other known pure transcriber (i.e.: one without word-matching or other post-processing).

The FEL Industries transcriber was used to process about two hours of signals obtained on Coast Guard frequencies. Some problems were encountered demodulating the signals on the audio tapes because of the inability to change receiver settings. Of the acceptably demodulated signals, 20% produced no meaningful output, 20% could be read and understood with no difficulty, and the remaining 60% produced transcripts which could be interpreted as to their general meaning, but where the confidence that could be placed on the details varied a great deal. The upper 80% of the signals were all copiable by an

experienced non-Coast Guard Ham Morse operator, but some presented difficulty. The lower 20% were not copiable at first, but after becoming familiar with the style of sending, the operator could eventually discern their meaning.

Some Conclusions

All of the projects reviewed here present useful techniques for application to the Coast Guard Morse code problem, but none can be used as it is without modification and further development. It is reasonably clear that some sort of confidence value technique should be employed, probably during and between all phases of the process. More work is still necessary on the demodulation components. No more theoretical work is necessary on the pure transcription components. A great deal of work is required on the "world knowledge" components since that is what appears necessary in order to successfully interpret most (i.e.: the lower quality 80%) of the Morse transmissions.

This conclusion, while initially discouraging, does not necessarily mean that a solution to the problem is so far removed as to be impractical. The history of Morse transcription development efforts is that they have not been oriented toward the overall problem to be solved, but rat[illegible]ave attacked particular sub-pieces that may or may not be repres[illegible] of the real issues involved. Many have been undertaken by re[illegible]s that did not understand Morse or that knew the dot-dash character combinations, but have never copied a signal off the air or operated a transmitter. Such persons could not conceivably be expected to have the insights necessary to put together a useful Morse system.

In addition, the problem is generally viewed as being "simple": "After all, it is only a series of dots and dashes. Certainly a computer can interpret _that_!" For this reason, it has not attracted widespread attention of knowledgeable workers, and organizations have not given it enough priority to fund any but small projects, thus further restricting the level of interest that is generated in the problem.

In all likelihood, the problem will remain unsolved until a coordinated project is undertaken which has as its goal the building of a complete operational system. Such a development program will not be cheap, nor is it guaranteed to succeed, but it is clear that until it is undertaken, there will be no significant breakthrough in the Morse interpretation problem. It is on the assumption that such a project may be undertaken by the Coast Guard that an overall design of an operational system is presented.

System Design Overview

A complete system capable of automatically interpreting Morse code transmissions must contain several components, all of which must be "experts" in their individual areas, and which must interact with one another to accomplish the overall goal.

The "extraction" components are those that extract the initial estimate of the letters represented in the signal that will then be used by later components. These consist of a component that will control the frequency, selectively, and levels of the radio receiver; process the signals into timing information; and convert this timing information into an initial estimate of the characters they represent.

The receiver control component should be straightforward to implement. Two techniques which should be explored to perform signal analysis, both of which have a high likelihood of success are: Linear Prediction analysis and a series of overlapping phase-locked loop decoders. Each of these would produce output which would then be processed by a signal separation phase which would determine the mark space timings. These timings are then processed by a transcriber constructed around the floating probability distribution concept.

The "understanding" components determine what words and phases are present using dictionary look-up, run-length sequences, and word construction techniques. These are then analyzed syntactically, semantically, and pragmatically within the context of a Morse radio operator "grammar".

Other components store global long-term and short-term knowledge and use this knowledge to guide the grammar. Additionally, components that allow human intervention, control and analysis are required as well as one which performs the logging function.

The grammar and knowledge components will require a significant developmental effort. Extensive work has been performed in these general areas by a variety of researchers, but none have applied their efforts to the Morse operator "language". While a large task, such an "expert" system should be realizable by modifying much of the existing work.

Coast Guard Morse Transcription - Preliminary Analysis
FEL Industries - January 1984

I. INTRODUCTION

This report discusses the possible use of automatic Morse code transcription techniques for U.S. Coast Guard operations. The primary purpose of such use would be in the automation of routine Morse code receiving tasks, in an effort to reduce personnel requirements. Such a reduction, if successful, would save on operating costs at two levels: the radio operators themselves and the personnel and facilities used to train these operators. Furthermore, the Coast Guard is experiencing increasing difficulty in recruiting radio operators. By reducing the need for Morse code skills, recruiting may be made easier, thus solving a potentially severe operational problem.

While this report takes a cursory look at personnel levels and training costs, the bulk of it deals with the operational and technical aspects of the Morse code transcription process as it relates to the Coast Guard. The reason for this emphasis is to try to determine, with some measure of certainty, whether or not automated transcription techniques are feasible for relatively near-term (one to five year) Coast Guard use. If not feasible, the cost considerations are irrelevant. If feasible, then a later project can determine the best way to actually integrate the automated transcription techniques, taking into account both technical and non-technical considerations.

Coast Guard Morse Transcription - Preliminary Analysis
FEL Industries - January 1984

The project of performing the analysis of the automatic Morse code transcription techniques has been broken down into the following tasks:

1. Analysis of Coast Guard Morse code operations
2. Analysis of the technical aspects of received Morse code signals
3. Evaluation of both of the above to determine the requirements of a transcription system that will meet the Coast Guard's needs.
4. Evaluation of existing transcribers and existing and potential transcription techniques
5. Recommendation of transcription techniques to be used by the Coast Guard.

The remainder of this report discusses each of these areas in detail.

<u>A note about notation</u>:

In this report, the word "dah" is used to represent the Morse Code dash and "dit" to represent the dot. If the dit is immediately followed by another mark (i.e.,: a dit or a dah), it will be written as "di". This is a widely used notation and is used because it most accurately represents what is actually <u>heard</u> when the code is sent. Thus for example, the letter "N" is represented by "dah dit"; the letter V by "di di di dah", etc.

II. COAST GUARD MORSE CODE OPERATIONS

The analysis of current Morse code operations performed by the Coast Guard was accomplished by:

1. Visiting a Coast Guard Communications Station
2. Reviewing various Coast Guard documents
3. Discussions with Coast Guard personnel
4. Analysis of audio tapes of Morse code signals received on Coast Guard frequencies as well as the corresponding logs

The following is a summary of Morse code operations within the Coast Guard, as gathered from the above sources:

A. Day-to-day Operations

A Coast Guard Communications Station may have one or more Morse code operating positions where an operator listens for signals on a specified radio frequency. The purpose of this monitoring is to insure that the Coast Guard can be contacted at all times by ships at sea. All relevant information is recorded by the radio operator in a log, and, when necessary, various information is relayed to other Coast Guard personnel.

When signals are received that are not directed toward the monitoring station, their content will be logged if a "complete" log is being kept. When the other form of log, an "abbreviated" log is being kept, only those signals actually directed toward the monitoring station are logged. The exception to this is that all distress,

urgency, or safety signals and related communications are logged regardless of who they are directed to. If no signals are heard during any five minute period, this fact is also logged when a complete log is being kept.

When a signal is received that is specifically directed toward the monitoring station, it will be logged and the operator on duty will reply to it. If the required communication is short, or of an emergency nature, it may be handled on the main monitoring frequency. Otherwise, the two stations will agree to move to another nearby frequency to handle the communications. If the move takes place, this fact and the associated communications are recorded in the primary log.

If a distress or urgency signal is received, the station supervisor will be notified of its existence, even if the signal was not specifically directed toward the monitoring station. Furthermore, such a signal will be answered by the receiving station whenever necessary to provide assistance or acknowledgement.

Other events that must be logged include the beginning and end of international distress frequency silent periods, time checks, operator name(s) at the start of each shift, additional equipment set up, equipment malfunctions, broadcast messages sent, and any communications active at shift changes.

B. Type of Morse Code Information Received

The information received by the Coast Guard over its Morse code channels varies in content from ordinary English sentences to coded groups of numbers representing weather data. In between these two extremes is the jargon employed by radio operators to establish and maintain communications and to transmit common information quickly.

1. Radio Operator Jargon

Some of the jargon is standardized to the point of world-wide acceptance (e.g.: "QTH?" is an international "Q" signal meaning "What is your location?"); others are agreed-upon abbreviations for English words or phrases (e.g.: "AB" means "all before"); and a large number are made up (often on the spot) by dropping letters from the English word (e.g.: the word "every" may be abbreviated as "EVRY").

The jargon is by far the most frequent type of signal heard by a Coast Guard operator, since this is the way communication is established and is the way common situations are handled quickly. For example,

NMF NMF DE SXGD SXGD GE QRU? K

means that NMF, a land based station (indicated by the three-letter call sign) is being called by SXGD, a ship (indicated by the four-letter call sign). (The "DE" means "from".) SXGD then says "Good Evening" ("GE"), "Have you any messages for me?" ("QRU?"), "Go ahead" ("K"). The sending of this entire message would probably take less than ten seconds.

2. Number Groups

Some of the messages received by the Coast Guard consist of a sequence of numbers that represent standardized weather abbreviation reports. These messages will frequently be sent as "cut" numbers in order to save time. "Cut" numbers are formed by sending one dah instead of a sequence of dahs, thus forming letters instead of numbers. For example, the number "1" (dit dah dah dah dah) would be sent as "dit dah" which is the letter "A". Cut numbers are only used in contexts where it is obvious that the information is numeric, so that no ambiguity usually results.

3. English Text

English text can be sent at any time, but occurs most frequently as part of a formal message for a third party. In such cases, there is a well-established format for the message along with procedures to be followed to insure that the message has been properly received. English text can also occur less formally during communications where the radio jargon does not adequately cover the situation. In these cases, it is likely that the English text and jargon will be mixed together within a single transmission.

C. Quality of Received Morse Code

The quality of the Morse code signals received by the Coast Guard depends on two major factors: the technical characteristics of the received signal and the clarity with which the sending operator forms the characters. Only the latter issue is discussed here, as the former is covered in detail in Section III.

Coast Guard Morse Transcription - Preliminary Analysis
FEL Industries - January 1984

Perfect Morse code is considered to exist when a dah is three times longer than a dit; and when word spaces are seven times longer than a dit, letter spaces are three times longer, and intra-character spaces are the same length as a dit. Good human-sent Morse code will come close to this standard, but such precision is never achieved in reality, especially at high speeds. Much more common, in fact, are wide deviations from the standard. Most operators do a good job of keeping their dits and dahs within reasonable proportion to one another, but do a poor job when it comes to the spaces.

It turns out that this lack of conformance to the standard space timings is usually not a problem, since it is often easy for a receiving operator to adjust to whatever the sending operator's "standard" is. Some problems arise, however, when the sending operator sends one type of space instead of another. A common occurrence is for operators to send letter spaces for word spaces or vice versa. Fortunately, in this case, all of the letters remain intact so that the message can still be read with only a little bit of difficulty.

A much more significant problem occurs when the sending operator substitutes a letter space for the space between the marks that form a letter. Such code is extremely difficult to understand unless the receiving operator has some preconceived notion about what is being sent. For example the message

DAH	DAH	DIT	DAH	DIT	DAH	DIT	DIT	DIT	DAH
T		K			R			U	

which was recorded on one of the Coast Guard tapes meant absolutely nothing in the context in which it was sent. However, when one realizes that the operator should not have inserted a letter space between the T and the K, DAH DAH DIT DAH or "Q" is formed and the message is the internationally recognized "QRU" signal.

In reviewing ten hours of audio tapes supplied by the Coast Guard, plus signals gathered by direct off-the-air monitoring of Coast Guard frequencies, it is estimated that approximately 20% of the operators exhibited the above characteristics. Furthermore, those who did this did it consistently and did not recognize it as an error or correct it.

Another type of spacing problem frequently encountered was when letter spaces were left out completely. This often happens for frequently used short words such as "the", and causes no problem since the sequence of marks is so common as to be easily recognizable. The problem becomes more acute, however, when this is done with uncommon words. In this case, it is extremely difficult to decipher the meaning.

We conclude from observing all of the above problems that the overall quality of the Morse code received by the Coast Guard is not good. The sending operators exhibit very sloppy habits which result in code that is difficult to read. Furthermore, when errors are made, they are almost never recognized and corrected.

D. Speed Range of Received Morse Code

The speed of the Morse code observed on the tapes supplied by the Coast Guard as well as heard directly off-the-air ranged from a normal low of approximately 15 to a normal high of approximately 25 words per minute, where a word is considered to be five characters.

Occasionally, an operator would be requested to slow down, in which case code in the range of 5 to 7 words per minute was observed. Also, when operators were sending familiar material such as the call-up to another station, the speed would go as high as 40 words per minute.

Except for the call-up procedure, most operators maintained a relatively uniform speed throughout a transmission or series of transmissions; however, it was not uncommon for an operator's speed to change gradually from the beginning to the end of a message. Occasionally, an operator would exhibit a "choppy" style where he would suddenly speed up in the middle of a word and then just as suddenly slow down. Such code is difficult to copy and can result in errors.

E. Experience Level of Coast Guard Operators

The experience level of Coast Guard operators can vary widely. An operator just out of school can receive Morse code at 16 words per minute as long as it is well sent and free of interference or noise. Such operators often can deal with signals at only half that speed when receiving off-the-air. After about a month and a half of

experience, these operators are usually able to receive Morse code at 16 words per minute under on-the-air conditions.

The best operators are able to receive code at the rate of 25 to 30 words per minute. This is usually accomplished after several years of experience. Such operators often move on to other non-operator jobs so that their numbers are small. The average operator, therefore, is capable of receiving approximately 18 words per minute of off-the-air Morse code.

No information is directly available on the error rates of operators. However, some insight has been gained by direct observation of operators and by the comparison of tapes of Morse signals with the logs of those signals kept by the operators. Specifically, the logs are only an approximation to the actual signals received. In fact, the log is much closer to what should have been sent according to established procedures than it is to what was actually sent. This may be done on purpose to make the log more meaningful to someone reading it later. However, operators were observed to have difficulty following some received signals and yet they still made complete log entries. In may cases, it is probably reasonable to believe that such entries by the operator as to the content of a signal are based on extensive experience and are valid. In other cases, it is equally reasonable to conclude that the operator is only partially able to follow what is being sent and that he is guessing at the rest of it.

It should be noted that the above refers only to the various items that are kept in the log such as call-up sequences used to establish contact and ask and respond to simple questions. It does not refer to the messages that are transmitted after initial contact is established. In this case, the receiving operator was often observed to ask for a repeat of a section of the message. Therefore, it is probably reasonable to conclude that the message portions of the Morse code signals are eventually received with a high degree of accuracy. As before, this is only educated conjecture since no direct data are available that can verify these conclusions.

F. Traffic Loads

The Coast Guard does not currently keep records which count the amount of received traffic on the Morse code channels. Therefore, without an extensive study, no quantification of current operations is possible. Note that for purposes of this project, we are only interested in received Morse traffic since it is that which will be dealt with by an automatic transcription system. A considerable amount of transmitted Morse code is handled by the Coast Guard, too. Much of this is in the form of broadcasts, the sending of which is already automated. When desired (i.e., when automatic transcription is in place), it will be a simple matter to automate all Morse code sending.

A 1978 study which summarized 1976 data (1) reported that ten stations received a total of 420,709 Morse code messages (as opposed to total signals received and logged, which should be many times

more). Since the Morse traffic is reported to be declining (but again, no hard numbers seem to be available), today's (1983) received Morse code message traffic should average out to be less than this.

Qualitatively, the limited sample of tapes that have been analyzed plus the additional off-the-air monitoring that has been done indicate that the number of stations using a particular channel varies from none at all for long periods of time to quite a few all at once. Personnel interviewed stated that during the winter months there is approximately a thirty-five percent increase in traffic over the summer months (which is when the tapes were made and the listening done). Furthermore, the traffic level fluctuates with the state of the economy and is currently at a low point. An increase of 100% or more is likely when the economy improves. Finally, each communication station has its own Morse code traffic level. Some have very little; others have large volumes. Unfortunately, as noted above, whether this large volume is in the range of 10, 100, or 1,000 messages per hour is not presently available.

G. Differences Between Coast Guard Receiving Stations

Aside from the traffic volume mentioned above, there is very little difference from one receiving station to the next in terms of the methods of Morse code operation, style of transmissions received, qualifications of operators, etc. What difference there is, is related to the radio frequency of the channel received due to the differing signal propagation characteristics of different frequencies. These differences mostly relate to the time of day when high and low volume traffic occurs.

H. Time-Related Differences in Operations

As mentioned above, the traffic volume tends to increase during the winter months. This is due to changes in shipping lanes and because severe weather results in more traffic.

Because of signal propagation, the number of signals received at night can increase significantly.

Finally, sunspot activity, which is cyclical over an eleven year period, can cause significant operational deviations. During high sunspot activity, the earth's magnetic field is disturbed causing radio conditions to become poor. When this occurs, signals can suddenly appear and just as suddenly disappear. Personnel interviewed indicated that communication during these times are kept as short as possible, but that even then it is often not possible to complete a conversation.

I. Special Operational Situations

Most special situations, such as severe weather and impending or actual labor disputes, simply result in a changed traffic volume. The exception to this is in time of war. In such situations, the traffic decreases since radio silence is to be maintained whenever possible. When traffic does exist, however, an extra burden is placed on the radio operator to understand the communications the first time it is received, rather than requiring it to be repeated.

Also, during wartime, a set of distress signals are used that are not used at any other time. Examples of these are:

SSSS	Attack by surface ship
MMMM	Mines exploding
AAAA	Attack by aircraft

Following these signals would be the ship's identification, location, and any additional information necessary for search and rescue. At present, most Coast Guard radio operators are unfamiliar with these special signals.

J. Number of Morse Code Operating Positions

Coast Guard personnel were interviewed and documents were searched to determine the number of Morse code operating positions. While there was some variation, the estimates were fairly consistent, with 20 to 25 being the approximate number of land-based positions and 60 to 70 being the approximate number of ship-based positions that are capable of Morse code operations. Somewhat less than this number would be in operation at any one time. While Coast Guard documents indicate procedures and frequencies for aircraft Morse code stations, no one interviewed knew of any aircraft that used Morse code in actual operations.

K. Personnel Requirements

Land-based stations typically operate a Morse code position in "guard" mode. That is, an operator is on duty listening all the time.

Each such position requires four billets to fulfill this requirement.

Ship-based stations maintain a guard on one Morse code frequency (500 KHz) while they are underway. A small number of ships have the capability to operate more than one Morse code position, but these are never operated around-the-clock. The ships keep abbreviated logs, so that the operator performs other duties while not attending to the Morse position. Therefore, it is unlikely that the required number of shipboard billets would be reduced if automatic transcription equipment were available.

L. Costs of Personnel

Radio operators are enlisted personnel whose military grade ranges from E-4 ($16,100 per year) to E-7 ($26,600). The average radio operator is an E-5 ($18,500 per year).(1) Therefore, the cost savings if automatic transcription existed would be:

Land based:
20 positions x 4 billets/position x $18,500 billet = $1,480,000/yr

Ship-based:
Probably none

An additional cost that should be considered, but which is difficult to obtain, is the cost of Morse code training. If transcribers were available, much of the Morse training could be eliminated.

---

(1)
These cost figures are based on COMDTINST 7100 "Annual Standard Personnel Costs" for Fiscal Year 1982 and represent the total savings than can be expected by the deletion of the billets.

M. Expected Changes

Operationally, the only significant change expected is that the volume of Morse code traffic will decline. However, it is likely that enough Morse operations will exist that the Coast Guard will have to maintain Morse capability for a long time.

Personnel and training costs are expected to increase as is the difficulty of recruiting radio operators. This latter issue is, in fact, one of the major reasons that the current project has been undertaken.

III. TECHNICAL ASPECTS OF RECEIVED SIGNALS

Various technical aspects of signals received by the Coast Guard have been analyzed to determine parameters that could affect the design of a Morse code transcriber. Tape recordings and live signals from the 500 KHz and 8364 KHz channels were used in this analysis.

A. Introduction to Morse code Reception

This discussion covers the basic situations that arise when receiving Morse code signals, in order that the remaining sections can be more meaningful to the non-radio operator. It is intended to be explanatory of phenomena observed rather than rigorously accurate. Technically oriented readers are asked to excuse some of the oversimplifications.

1. How the Receiver Works

In order to understand the problems of Morse code reception, it is necessary to understand a little bit about how the radio receiver interacts with the transmitted signal or signals to produce the audio tone that is heard from the speaker. Radio signals that are heard over the home broadcast radio consist of two parts: a carrier and modulation. The modulation contains the voice or music. If this stops, what is heard is nothing, i.e.: silence. In this case, the carrier is still present. If the carrier is turned off, a jumble of

background noise and other stations is heard, similar to when no particular station is tuned in. Turning the carrier back on would eliminate the background noise and again produce silence. This is in fact what Morse code actually is: the rapid turning on and off of the carrier.

But simply turning the carrier on and off produces a "thump-thump" sort of sound interspersed with noise; that is, it doesn't sound anything like the "beep-beep" associated with Morse code. The reason for this is that special circuitry in the receiver is necessary in order to produce this latter sound. Specifically, a new signal (called a "beat" signal) is generated by the receiver and mixed with the incoming signal in such a way that a new signal is produced. This new "audio" signal can then be heard by the human ear. The frequency (i.e: pitch) of this new signal is determined by the difference between the incoming signal and the beat signal. Thus, changing either one will cause the frequency of the audio signal to change. In practice, the beat frequency is changed by adjusting the "Beat Frequency Oscillator" or "BFO" knob on the receiver. The frequency of the incoming signal is changed by adjusting the main tuning knob.

2. Multiple Signals and Receiver Bandwidth

Suppose a signal is being transmitted on a particular frequency, and the BFO is set so that an audio tone of 1000 Hz is produced on the speaker. If another signal is then transmitted on a frequency 100 Hz higher than the first signal, then it would be heard as a 1100 Hz

audio tone. If a third were transmitted on a frequency 50 Hz lower than the first, then it would be heard as a 950 Hz tone. Thus, if all three signals are being transmitted at the same time, then they all would be received at the same time, each one distinguishable by the pitch of the audio tone. (Note that if two signals are on the exact same frequency, they will have the same audio tone, and it is virtually impossible to distinguish between them.)

The range of frequencies on which signals can simultaneously be received is dependent upon a receiver's "bandwidth". The larger (wider) the bandwidth, the more frequencies that can be received; and the smaller (narrower) the bandwidth, the fewer frequencies that can be received. Most Morse code receivers have knobs for controlling the bandwidth.

As the bandwidth of the receiver is reduced, it often becomes easier for the operator to pick out the desired signal. However, there are situations where it is desirable to use a wide bandwidth even though a lot of undesired signals will also be heard. In this case, the operator depends on his ability to discriminate between the various audio pitches to pick out the signal he wants. In fact, this is almost always the case anyway, since no matter how narrow the bandwidth, it is still likely that other signals will be in it during busy times.

3. <u>Interference</u>

The radio frequencies monitored by the Coast Guard are used internationally to establish communications between ships and land. While there are rules and treaties that govern the use of these frequencies, there is no centralized coordinating control station. Thus, each station fends for itself in attempting to communicate with another. This results in many stations transmitting simultaneously within a small range of frequencies. When this happens, the stronger signals will so dominate that it will be impossible to determine what the weaker ones are saying. Also, there may be so many signals present that sometimes one interferes, then another, then another, etc. so that the weaker one is still blotted out. Sometimes, this multitude of signals results in a situation where none of them is intelligible.

4. <u>Frequency Spread</u>

The fact that the various signals are distinguishable at all is due to the fact that they are not all transmitting on the <u>exact</u> same frequency, even though they all <u>intend</u> to be. This is due to the fact that the mechanisms for controlling the frequency generation components in most shipboard transmitters are not precise, and can be affected by many factors, including temperature and humidity. Thus, signals intended to be transmitted on a particular frequency could be as much as 300 to 500 Hz away from it. Such signals may not be heard by monitoring stations if the bandwidth of the receiver is set to be too narrow.

B. Strength of Signals

The signals received by the Coast Guard vary from the weakest possible that can still produce a tone in the speaker to those that are so strong that the volume must be turned down for comfortable listening. As long as there is only one signal present, it can be understood by the operator even if it is extremely weak. Even a moderately strong signal or two on nearby frequencies may not render the weak signal unreadable. However, when there are many signals present that are moderate or high strength, then it is unlikely that the weak signal will be heard.

This could be due to any of the factors already mentioned or to the "overloading" of the receiver. Overloading occurs when signals are so strong that they cause distortions of themselves and other signals. When this happens, it is necessary to reduce the sensitivity of the receiver to the point where the distortion is eliminated. With this reduced sensitivity, some weak signals are no longer heard that previously might have been.

C. Fading

Radio waves take various paths to go from the transmitter to the receiver. These paths change from time to time, causing a variation in signal strength called "fading". This fading can sometimes be very rapid - so rapid that the signal will go from strong to weak and back again within the time period of only a few Morse characters. Normally, the fading is of a slower duration, but even so it is common

for it to occur over the period of a single message exchange. Sometimes the depth of the fading is so severe as to cause the signal to disappear completely, only to return several seconds (even minutes) later. Sometimes, too, the signal never returns after a fade, and communications are lost.

Fading is caused by a variety of factors, and thus not all signals are affected equally. It is possible for a fade to affect all of the signals of a given frequency more or less equally so that when one fades out, they all do. Just as common, however, is the situation where a signal fades out and another signal, perhaps not even previously received, fades in. Fading, especially if severe and frequent (such as occur during times of high sunspot activity), can therefore have a disruptive effect on communications.

D. Signal Bandwidth

Morse code signals occupy a bandwidth of approximately 300 Hz. Therefore, many signals can appear within the bandwidth of a receiver, which can typically vary from 400 Hz to 16 KHZ, depending on the operator's setting.

E. Audio Frequency Range

Since the tone heard in the speaker is the difference between the actual signal and a reference signal generated by the receiver, the audio frequency range is a function of the circuits which generate the reference signal and the fidelity of the audio components of the receiver. Audio frequencies normally vary from 100 to 5000 Hz, and, as mentioned in section III.A.1., can be adjusted by the operator.

F. Tone Quality

Tone quality refers to the "purity" of tone and is usually a function of the quality of the transmitter. Poor tone quality would sound raspy or even like a buzz. None of the signals heard seemed to be intrinsically of poor tone quality. Personnel interviewed indicated that such signals are very rare.

What was heard, however, were signals that sounded raspy due to the adjustment of the receiver. This usually occurs when the bandwidth is narrow and when a strong received signal is not near its center. In this case, distortion results causing an impure tone to be produced. This is easily corrected by reducing the sensitivity of the receiver or widening the bandwidth, both adjustments which are under control of the operator.

G. Frequency Shift (Chirp)

Chirp is caused by a transmitter that changes frequency slightly during a single dit or dah. Normally, chirp does not cause any difficulty for the receiving operator, and occasionally even helps by making it easier for the operator to identify the signal. Several cases of chirp were observed on the sample tapes as well as heard directly off-the-air. The range of frequency shift was approximately 50 to 100 Hz. In extreme cases, the shift could conceivably be as much as 300 Hz.

H. Clicks

Turning the transmitter on and off so rapidly that an undesirable wave form is produced causes loud clicks to appear before and after the tone representing the dit or dah. Such clicks are quite annoying to an operator especially if they are generated by a signal that he is not interested in, since they can easily overpower his desired signal. Since clicks represent energy transmitted over a broad frequency range, there is usually nothing that the receiving operator can do about them.

No signals on the tapes or off-the-air were observed to have clicks. However, personnel interviewed indicated that such signals occasionally appear.

I. Operational Note

In the preceding discussion, it was mentioned that there are various controls that an operator can use to better receive a signal. That is, he can: adjust the BFO or incoming signal frequency to control audio pitch; adjust the bandwidth to receive a wider or narrower range of signals, depending on conditions; adjust the sensitivity to control overloading; adjust the audio volume for comfortable listening.

During actual monitoring, these controls are placed at one setting and left there for long periods of time. The frequency, BFO, and bandwidth are practically never changed. The others are usually changed as general signal conditions change. The reason for this is

that there simply isn't time. That is, by the time an adjustment was started, the transmission would probably be over. Therefore, the operator picks settings which he feels are optimum for the conditions and then attempts to interpret whatever comes through.

IV. TENTATIVE REQUIREMENTS FOR A MORSE TRANSCRIBER

Having investigated the operational and technical details of the Coast Guard's Morse code operations, some tentative proposals can be made regarding an automatic transcriber that could fit into that environment.

A. Signal Handling Capabilities

It is clear that the signals received by the Coast Guard include some that are technically and operationally terrible, some that are excellent, and many which are in between. It is tempting to say that in order for a transcriber to be useful, it must do as well as a human can do but, as pointed out in Section II.E., it is not known how well (or poorly) humans really do. Furthermore, do we choose the best human's performance; the worst; or one in between?

From a practical point of view, a useful transcriber must be able to deal with all of the various types of signals: too strong or too weak ones, fading signals, ones with chirp, buzz or clicks, and ones which are keyed by poor operators. In addition, it must be able to deal with multiple interfering signals and atmospheric noise. It must be able to handle these in a manner that will allow it to accurately transcribe a large percentage of the desired messages (say 90%), without assistance of any kind. (It is doubtful that there are many human operators who can consistently achieve this rate.)

If a transcriber is able to do this, then the Morse code operation becomes very similar to that of radio teletype, where the operator does not know the transmitted code but does know the various radio communications procedures.

B. Essential Operational Requirements

In order to understand the 90% figure in the preceding section, it is necessary to define what is meant by the "desired messa es". In the Coast Guard environment, there are four types of "desired messages":

1) Distress, urgency or safety calls
2) Signals that represent calls to monitoring stations
3) Any other signal if a "compete" log is being kept
4) Formal third-party message traffic

The first three represent the signals that must be transcribed and at least partially understood in order for a transcription system to take over Morse radio operator functions. The first two signal types must be recognized so that an operator can be summoned to handle the communications exchange itself. The third signal type must be understood enough to recognize that it is not one of the first two types, but simply a signal that is to be entered into the log.

The ability to adequately handle these three message types would make it possible to use the transcription system to constantly guard one or more frequencies. This would result in major personnel cost savings, would reduce training costs, and would make recruiting easier since Morse code training would probably become an elective rather

than a requirement. As such, most of the Coast Guard's objectives would be met.

It is hard to imagine how handling any <u>less</u> than the first three message types in the manner stated could be at all useful to the Coast Guard. Therefore, these are regarded as <u>essential</u> operational requirements that any successful transcription system must meet.

C. <u>Desirable Operational Characteristics</u>

If the fourth type of message mentioned above could be handled well by the transcription system, then it would be possible to entirely eliminate the requirement for on-site Morse-qualified personnel. In other words, if the system could transcribe English and other types of text found in message traffic as well as all of the special procedural jargon, then an operator could read the output and respond to it using an automated real-time Morse code encoder. (Such an encoder would probably be built into the transcriber, since all of the mechanism required for it to operate would already exist, and the additional processing required would be minimal.) Then, Morse operations would no longer require anything beyond the skills of a teletype operator since all messages would be received on a printer and transmissions would be entered on a keyboard. This ultimately is a highly desirable goal, but is not an essential requirement for a transcriber to be useful to the Coast Guard.

The remainder of this report discusses some technology that already exists as well as what must still be done in order to accomplish these goals.

V. ANALYSIS OF COMMERCIALLY AVAILABLE MORSE CODE TRANSCRIBERS

The analysis of fifteen commercially available Morse code transcribers was accomplished by:

1. Reviewing advertising literature, technical specifications, operating manuals, and block diagrams supplied by the manufacturers.
2. Discussing operational and technical characteristics with the manufacturers.
3. Using actual Morse code signals received on Coast Guard frequencies in an on-line evaluation.

Not all of the above were used for each of the units evaluated. Appendix A lists the manufacturer and model number of each of the units and how each was analyzed.

A. Overview of the Transcribers

Before going into detail about the technical aspects of the transcribers, it will be useful to understand their purpose and style of use. Both of these are determined by their intended market which is primarily the amateur "ham" radio operator. A secondary market for some of the units is in the area of Morse code training.

1. Purpose

Because of the market characteristics, the commercially available Morse code transcribers are designed to be an aid to the human operator rather than as a replacement. Specifically, their purpose is to allow the operator to copy machine-sent signals or signals that are

faster than he would normally be able to copy, usually with the goal of increasing the operator's proficiency rather than accurately transcribing entire signals or messages. They do this by producing a display of characters that are read while the signal is heard. To the degree that the characters are an accurate representation of the Morse signal, the amount of character-by-character decoding that the operator must do is reduced, which then frees him to more fully concentrate on those characters that are the most difficult for him. Furthermore, even when the transcriber is not correctly decoding every character, it may be decoding enough so that a context is established in which the operator can anticipate what the characters are. By so doing, he is then able to verify that the characters are or are not those expected, even though they are being sent faster than he can normally receive. In all of this, the effect is to reinforce the associations between the Morse sounds and the characters they represent, thus ultimately improving the operator's receiving ability.

2. Style of Use

The style of usage of all the transcribers is similar: The operator manually tunes the radio receiver to the signal he wishes to receive until an indication is given by the transcriber that it is processing the signal. This is usually shown by a small light which flashes in synchronization with the Morse signal. Shortly after this synchronization is achieved, characters are displayed which represent the transcriber's decoding of the signal.

Some of the transcribers have the ability to display the speed of the received signal (in words per minute); some have micro-computers associated with them that allow the filing and editing of the received text, as specified by the operator; some have the ability to also receive radio-teletype and slow-scan television signals. None of these additional features alter the basic capability of the Morse code transcription portion of the device insofar as extending the type or quality of signal that can be handled nor do they alter the basic style of use.

3. Relationship to this Project

When this project started, it was believed that the goals of the commercially available transcribers were similar to the goals of this project and that it might be possible to find one that would come close to meeting the technical and operational requirements of the Coast Guard. It is now evident that the goals are not the same and that no such commercially available unit exits. (This will be more thoroughly explained later).

The evaluation of these units, while unfortunately not resulting in devices that the Coast Guard can directly use, has nevertheless provided valuable insight about what techniques may or may not be useful in its environment. Furthermore, using these devices in actual on-the-air tests has clarified issues that may otherwise have remained unresolved.

The major difference between the start of the project and when this phase concluded was that the units were no longer being compared

and contrasted against one another in a selection process. Rather, the generic characteristics of the units were evaluated to determine their applicability to the Coast Guard environment. As such, reference will not be made to specific manufacturers and models, but will be made only to the various units' general operational and technical characteristics. Finally, nothing in any part of this report should be construed as an evaluation or criticism of these devices for their intended purpose in their intended markets, as they have not been analyzed from that point of view.

B. General Operation

This section describes how the transcribers work in general. No one of the transcribers analyzed may match the exact description, nor perform the functions in the exact order, but they all perform essentially the same tasks.

Any conventional Morse code radio receiver may be used to produce an audio signal that is then processed by the transcriber. To achieve this, the receiver speaker or headphone output is connected directly to the transcriber input. This audio signal normally contains many different tones representing Morse code signals (see Section III.A.2 of this report), only one of which is the desired one.

One of the first things the transcriber does is to use some means to select the one desired signal from all of the rest. Next, the selected signal is converted from its audio form into a series of on-off pulses which can be processed using a small digital micro

computer. These pulses are on when the signal is present (referred to as a "mark") and are off when no signal is present (referred to as a "space"). The steps up to this point are collectively called "demodulation".

The "timing" phase takes place next, in which the on-off pulses are measured to determine their duration. If extremely short marks or spaces are detected, they are assumed to represent noise. At the completion of this step, all of the noise, interference, fading, etc., has been eliminated and the decision has been made as to when a mark or space is present in the signal and how long each one lasts.

The mark and space durations are then analyzed by the micro computer to determine which of the marks represent dits or dahs, and which of the spaces represent word, character, or sub-character spaces. This information is then matched against a table of Morse code characters and the resulting characters and spaces are displayed. This "decoding" phase completes the transcription process.

C. Description and Analysis of the Techniques Used

1. Demodulation

Two techniques are used to convert the audio signals that are output from the radio receiver into on-off pulses that can be processed by the micro-computer:

a. Envelope Detector:

An envelope detector is an electronic circuit which indicates a mark whenever the audio input voltage rises above a certain level. Such a circuit may perform well in relatively noise-and-interference-free environments, but has many shortcomings otherwise. Specifically, if there are several signals in the bandpass of the receiver, the loudest one will usually trigger the envelope detector. As fading occurs or other stations begin operating nearby, the signal which is the loudest will change, producing unpredictable results. Then, too, the signal desired is not always going to be the loudest one in the pass band.

In an attempt to correct the above deficiencies, various kinds of filters have been added so that only a very narrow band of audio frequencies can reach the envelope detector circuit. This helps a great deal in reducing the interference problem, but creates another problem. That is, to be effective the bandwidth of the filter must be very narrow - on the order of 100 Hz. With such a narrow bandwidth, tuning in a signal is quite difficult because of the precise receiver adjustment required. If the transmission is of short duration, as are most of those received by the Coast Guard, it will be over before the adjustments can be made.

Even if a signal is finally tuned in so that there are no other interfering signals, a serious problem still remains with the envelope detector concept. That is, that it will trigger on any signal that rises above the given voltage level, including static pulses and

background noise. Since the intensity of this type of noise is constantly varying, frequent false triggering is caused, especially if the desired signal is not strong relative to the noise to begin with.

Because of all of these problems, it is concluded that the envelope detection demodulation technique is not appropriate for the Coast Guard Morse code environment.

b. Phase-locked Loop:

A phase-locked loop (PLL) is an electronic circuit which indicates a mark when an audio tone is detected which is close to a specified reference frequency. As soon as this happens, the circuit synchronizes itself with the tone and maintains the synchronization even though the tone may change frequency somewhat. If the tone strays too far from the reference frequency or goes away, then the PLL is no longer in synchronization and as a result a space is indicated.

Since the phase-locked loop is sensitive to the frequency of the received Morse code tone rather than to its voltage level, the problem of sensing weak signals is significantly reduced, as is the problem of selecting one signal among many in the receiver's bandwidth.

The phase-locked loop shows markedly better performance than the envelope detector although some of the problems remain. Specifically, precise tuning is still necessary since the PLL operates over a fairly narrow frequency range. Furthermore, stray noise pulses sometimes trigger the circuit although this is not nearly as objectionable as with the envelope detector circuit. Because of these problems, it is

concluded that the phase-locked loop technique as implemented in the commercial transcribers is still not adequate to handle Morse signals in the Coast Guard environment, primarily due to the requirement for precise tuning by the operator. However, an adaptation of the technique may be viable. This is examined more closely in Section VII.A.2.b.

2. Decoding

All of the transcribers use essentially the same technique for converting the mark and space durations into characters. The technique involves establishing three threshold values: one between the two types of marks and two between the three types of spaces. Once the thresholds have been established, the marks and spaces output from the demodulation phase are classified as to type based on whether they are above or below the appropriate threshold. Once this classification is complete, a table of Morse code characters is used to determine the character to display. Finally, all of the thresholds are updated to reflect the new classification so as to allow the technique to adjust to any speed variations that may be present.

This technique has been tried by many experimenters ever since the mid-1950's and has universally produced the same results: it works very well for machine-sent and carefully-sent hand code, but produces disappointing results on most hand-sent Morse code that is actually on the air.

The reason for the failure of this technique is simple: Morse code marks do <u>not</u> fall neatly into two groups of dits and dahs nor do spaces fall into three groups of word, character, and sub-character spaces. Rather, in most hand-sent code there is significant overlap between the groups and <u>no matter how cleverly the thresholds are set</u>, at any given point in time, there exists <u>no</u> setting that can accurately discriminate the marks and spaces that have <u>already</u> been identified, much less precisely classify an <u>unknown</u> item. This conclusion has been discovered and reverified by many experimenters, some of which are given in references (2), (3), and (4). When the transcribers were tested with signals received on Coast Guard monitoring frequencies, this conclusion was found to be particularly true because of the exceptionally poor quality of the Morse code received, as discussed in Section II.C of this report.

D. Conclusion

Our conclusion on the use of the commercially available transcription devices is straightforward: none of them are appropriate for use in the Coast Guard Morse code operating environment, and only one of the techniques used in them (phase-locked loop demodulation), has promise for applicability to the problem.

VI. ANALYSIS OF EXPERIMENTAL RESEARCH PROJECTS

Several experimental research projects have taken place in university or government settings which have addressed aspects of the Morse code problem. These systems have attempted to solve a more sophisticated problem than that solved by the commercial transcribers, so their results are more likely to be of benefit to the Coast Guard.

The nature of these research projects is that they have addressed a sub-part of the overall problem, rather than attempt to build a complete system. Therefore, it is not possible to run tests on them to determine their usefulness as was the case with the commercial transcribers, but it is possible to review their published research results. Two such projects, one at the Naval Postgraduate School and another at the Massachusetts Institute of Technology are reviewed here. The reports reviewed, while differing in perspective and detail, provide an illustrative cross-section of the state-of-the-art research on the Morse transcription problem.

The two projects mentioned above are (or were) not by any means the only ones active. Several such projects also exist (or existed) within various of the U.S. Intelligence agencies, and this investigator has had personal contact with and has visited two of them. Reports on these projects are not available, presumably because of their classified nature. However, it is the opinion of this

investigator that if such reports were available, they would add little to the state-of-the-art as known by the unclassified world.

The final project that is reported on here is one that has taken place in our own laboratory at FEL Industries. We are not aware of any other private (i.e.: non-governmental or non-university) organization doing work in this area. (Except of course, for those companies which produce the commercial transcribers, reviewed above.)

A. Naval Postgraduate School

The research report reviewed here, "Optimal Bayesian Estimation of the State of a Probabilistically Mapped Memory-Conditional Markov Process with Applications to Manual Morse Decoding (5), is an attempt to provide a mathematical model of hand-sent Morse received over a noisy communication channel.

After describing the Morse code problem, the author develops an entropy model which provides lower-bounds on the receiving error rate, given various assumptions. Next, he develops a general mathematical model which accounts for message context, sending operator errors, variation in speed, and variation in the mark/space durations. Once this theoretical model is constructed, it is shown that it is not realizable in practice, due to exponentially expanding memory requirements. However, suboptimal practical realizations are discussed and it is shown that it is possible to approach the optimal realization as a limit (but again, as a theoretical rather than as a practical matter). Finally, an implementation of an actual signal and communication model is presented, along with an analysis of test results.

It is doubtful that the mathematical model or the specific computer program developed by this research will ever find its way into practical application. The model itself is much too compute-intensive to be practical, and the program exhibits disappointing results when run with test cases. However, the research is useful in that it presents a vigorous mathematical argument that says that we can, in theory at least, do as well as can be done in the Morse code receiving task by using a probabilistic approach. This approach would work by assigning probabilities of occurrence to each of the many variables intrinsic to the problem, and then by calculating the most probable message through the use of these probabilities, combined in such a manner that each probability provides appropriate feedback to each of the other possibilities, such that the system converges and produces the desired result. This result, then, provides us with an "existence proof". That is, given enough resources it is possible to solve the Morse code problem. As with most mathematical existence proofs, however, it is not constructive. That is, it only tells us that it is possible, not how to construct a system to actually do it.

The reason for this is that the model assumes the existence of certain functions that will estimate the probabilities of each possible outcome for things such as keystate, speed variations (or not), letter sent, message context, etc. Then, given the existence of functions to produce the probabilities, the model can appropriately combine them (given enough time and space). The problem is that it is not known how to develop these individual functions. In fact, the

author hypothesizes that the more complex, and possibly all, of these functions must be developed uniquely for each operator on-line while the communication is taking place. Not mentioned by the author is the likelihood that if we know how to do that, we wouldn't need such an elaborate model to combine the results!

Notwithstanding the above problem, this research still provides an interesting framework within which to view the Morse code transcription problem. Specifically, no one event or even sequence of events can be known to have occurred with certainty, and judgments must be made based on other events (which are also subject to uncertainty) as to what the event or sequence actually represents. It is likely that much of these judgments can be made by bringing to bear extensive amounts of "world knowledge" such as the syntax of a message call-up sequence, the meaning of various station's call letters and how they relate to the likely content of the message traffic, etc. At some point, after all of this world knowledge has been applied, there is still likely to be some uncertainty remaining which can be expressed as a probability (or more accurately, as a heuristic "confidence value" rather than a mathematically rigorous probability) which can then use a probalistically based model such as the one presented here to resolve any remaining conflicts.

B. Massachusetts Institute of Technology

This report, "Computer Transcription of Hand-Sent Morse Code Using Properties of Natural Language" (6), is an attempt to apply the notion of world knowledge mentioned in the previous section.

The problem dealt with is the "segmentation problem". That is, when a spacing error is made by the sending operator, it usually produces results that significantly obscure the meaning of the message (see Section II.C. of the current report). Such errors occur frequently enough and over a wide enough range of operators such that it is a major problem that must be solved in order for a transcriber to be useful. Three techniques are employed to help solve the problem:

1) the confidence value concept mentioned at the end of the previous section
2) "Run-length sequence", which is the representation of a word by the Morse code marks that comprise it, leaving out any space information
3) English language redundancy

1. Confidence Values

Instead of simply classifying a mark or space based on whether it is on one side of a threshold or not (as mentioned in Section V.C.2 on the commercially-available transcribers), values between 0 and 1 are assigned to the mark or space based on how far the item is from the average value of the same type of item. Thus, if a new item fell right on the mean, its confidence value would be 1, and if it fell right on the threshold, its confidence value would be 0. These confidence values are then passed to the next processing phase which may alter them individually if additional knowledge is gained about their probable classification, and which combines them to form an overall confidence value for a series of items. During these later phases, this overall confidence value is used to determine which possible decoding should be pursued and which should be dropped from consideration.

2. Run-Length Sequences

The Morse message is then broken up into a series of "blocks" which are sequences separated by high-confidence spaces, assumed to be word spaces in the final decoding. Then, each block is processed to determine those run-length sequences that best fit it. Since there may be several sequential or overlapping run-length sequences that fit each block, a record is kept of which ones produce the "best" fit based on the confidence values.

The benefit of fitting run-length sequences to the blocks instead of using individual letters is that the run-length sequences have a high degree of uniqueness. This is because there are far fewer legitimate words (which the run-length sequences represent) than there are possible combinations of letters, and because a given run-length sequence represents a very small number of words. For example, in the 1300 word dictionary used at MIT, 95% of the run-length sequences represented only one word, and the highest number of words represented by the same run-length sequence was 3. Therefore, the number of combinations that must be considered by using run-length sequences instead of individual letters is considerably reduced, and spacing errors which occur within the run-length sequence will not (in theory, at least) have as severe an impact on the overall decoding of the message.

3. English Language Redundancy

Even with the run-length sequence technique, though, there are still quite a few possible interpretations of a message. In order to

determine which of the interpretations is correct, they are analyzed using a simple English language grammar. If an interpretation is found that is not grammatically correct, its confidence value is lowered according to how incorrect it is. At any given time, the interpretation with the highest overall confidence value is the one used to continue processing the message. That interpretation which provides the highest confidence value when the end of the message is reached is the one chosen as the correct interpretation.

4. Results

It is difficult to analyze the results of this project as presented in the report since the test cases were not at all representative of actual on-the-air signals. The test cases consisted of relatively inexperienced operators sending at a fairly low speed (i.e., they sent considerably better code than a real operator would send) in clear-signal laboratory conditions. The "messages" were English text, mostly taken from the Declaration of Independence. While not explicitly mentioned in the report, it is likely that all of the words contained in the messages were also contained in the run-length sequence dictionary, and that all of the grammatical constructions were known by the English language analysis program.

The analysis in the report shows that the project's transcriber did perform better than one which uses techniques similar to those described for the commercially available transcribers. However, the transcripts of the messages produced by the less-sophisticated transcriber were quite readable already, and were far better than most

of the messages received on Coast Guard channels. Therefore, the actual results produced by this project are inconclusive, at best.

5. Analysis

More important than the actual results produced, though, are the concepts employed. Each has significant merit, and should not be ignored when considering the design of a transcriber. The notion of confidence values has been explored in some depth in Section VI.A. of this report and won't be reiterated again here.

The run-length sequence concept may have applicability toward solving the segmentation problem as suggested in this report as long as the context of the message is taken into account. That is, the word dictionary is going to be significantly different depending on the type of transmission (call-up, chit-chat, weather report, formal third-party traffic, etc.). Certainly, using an English language dictionary of words will do little good (and would probably be harmful) if used for anything other than clear text. However, a dictionary with the international Q-signals and common abbreviations would probably help quite a bit during the call-up and negotiation phase of message handling.

Knowing when to switch between one dictionary and another (i.e.: knowing the context of the transmission) is the information that can be provided by a properly designed "Radio Operator" (not "English") grammar. That is, in addition to helping establish confidence levels about the correctness of a particular interpretation of a

transmission, the grammar could also help determine its context as well.

C. FEL Industries

The FEL Industries experimental Morse system was built in order to provide a framework within which various techniques could be tested and analyzed. It has been built as a series of components so that a variety of techniques can be tested in one component while keeping the others the same. In this way, it is possible to continuously upgrade the performance of the system as better techniques are found which accomplish the job of each component.

A fundamental tenet of the system since its inception was that it must function in an active on-the-air Morse environment, since that is the only environment in which a solution to the problem is at all meaningful. This bias is reflected in the fact that the primary input to the system is through a radio receiver and all of the programs and techniques used have been developed, tested, and debugged using signals gathered off the air -- signals sent by operators who were actually trying to communicate with one another and who had no knowledge that an automatic system was attempting to decode their transmissions. This single bias on focusing on the real problem domain (rather than using simulated code or laboratory sent code, as used in the first two projects reported on) will in all likelihood be the most important single ingredient in building a successful operational system.

In addition to using real data, the above constraint also implies that the system must function in real-time. That is, the translation of the Morse signal must be printed out with no more delay than that exhibited by a human radio operator. Adopting the real-time constraint insures that the techniques and programs developed are focused toward an eventual operational system. While it is often desirable to test theoretical issues in a manner that many not produce real-time results (which was the case in the two previous projects reported on), knowing that they eventually must be embodied in an on-line real-time system forces attention to the more practical aspects of the problem.

1. The Morse Laboratory

The experimental Morse laboratory consists of several radio receivers, a transmitter, an antenna, several tape recorders, and miscellaneous testing and monitoring equipment. This equipment is linked to both micro and mainframe computers, and a patch panel provides convenience and flexibility in configuring, debugging, and operating the system.

The signals from the receiver are tape recorded and simultaneously converted into on-off logic signals by one of several analog methods (described later in the Signal Processing section) which are built into a piece of hardware called the "Multi-Function Box" (MFB). The logic signals output from the MFB are then timed by a 1 kHz clock built into the micro-computer. The timing durations and other relevant data are then sent to the mainframe computer system (a

DECsystem 2020) where they are stored on a disk file. This disk file serves both as a real-time buffer and as a permanent repository for the timing data. Thus, all data output from the MFB is automatically saved so that if it contains errors or interesting features, it can be analyzed in combination with the audio tape of the signal it represents and used as the basis for program changes.

At the same time that the disk file is being built by the signal analysis and timing components of the system, another process (described later in the Code Transcription Section) is reading that same file and is analyzing its contents to determine what Morse code characters are present. These characters are then printed on a typewriter terminal and the process is complete.

When building a system of the complexity envisioned, it is necessary to devote considerable energy to the analysis of the characteristics of the input data and of the results obtained from each of the components. Such analysis is the key to developing insights necessary to enable the construction of successful techniques. This analysis often can not be done by simple contemplation or by the scanning of a few test cases. Instead, it is necessary to look at large amounts of data and to experiment with various transformations of that data. Needless to say, the computer is the ideal tool to aid in this analysis problem, and considerable effort has been expended to develop programs which interact with the various components of the system to provide the required analysis capability.

The first set of such programs use as input the timing data stored on the disk files. One program formats the raw data so that it is easy to determine the timings of the various signals. Another uses a graphics system to display histograms of mark and space timings during selected portions of a signal. Samples of these histograms are given in Appendix B. Finally, it is often the case that the only way to determine if the various components are functioning correctly is to listen to the signals they produced (in the case of the signal processing components) or that they processed (in the case of the transcriber). For this purpose, a program was built which plays back segments of the timing data stored on the disk. This data can be played back at the original speed of the sender, or can be sped up or slowed down as desired.

Another set of analysis programs which have been used is concerned with the digital processing of the audio waveforms to extract parameters from them which will indicate if one or more code signals are present, and if so, when. The programs have provided several variations on the basic Fast Fourier Transform form of processing as well as some special Linear Prediction techniques normally used for processing speech signals. The results of these programs, examples of which are given in Appendix C, have been displayed on a graphics system in order to get insights into what happens to the desired signal when various phenomena occur.

2. Major Components Implemented

a. Signal Processing

Four techniques have been explored for converting the analog signals into on-off pulses that can then be processed by a digital computer. Each are described here briefly.

The first of these is an envelope detector which indicates a mark whenever the audio input voltage rises above a certain level. This was adequate to enable initial testing of the transcription algorithms, but it suffers from the same problems mentioned in the section on commercial transcribers: false triggering by noise and not triggering properly with weak signals or when they fade or drift.

The second technique is the phase locked loop (PLL) which locks onto a signal when it is close to a specified reference frequency. As long as the voltage level stays above a fairly low level and the frequency stays within a fairly narrow bandwidth, the PLL will trigger well. Thus, the problem of sensing weak signals is somewhat solved and the problem of slight drift is also solved. It was found that it is necessary to make the bandwidth of the PLL wide (relatively) in order to minimize the lock-on time. (If the lock-on time is too slow, the mark/space timings are distorted and can become meaningless.) With the wide bandwidth, the problem of false-triggering on noise remained, although it was not as bad as with the envelope detector. Even with the relatively wide bandwidth, the problem still exists that the bandwidth of the PLL is so narrow that manual tuning of a signal is quite difficult.

To solve this, two PLL's were combined so that they overlap in frequency. Attached to the output line of each PLL is a light emitting diode (LED). Only when both LED's are lit is the signal centered in the passband. If only one is lit, it indicates the direction the receiver should be tuned for proper centering. The outputs of the PLL's are combined, causing a mark to be indicated whenever the signal is present in either passband. Thus, easier tuning has been achieved while maintaining the other good characteristics of the PLL. This two-loop system has been used quite successfully, but it still has the noise problem, is sometimes overloaded by the existence of stronger signals, and can't lock onto extremely weak signals.

The fourth technique studied is the use of real-time digital signal processing techniques. The audio waveform has been digitized using a high-speed signal processing computer, and then this digitized waveform has been subjected to one of several variations on the FFT form of processing and to some special Linear prediction techniques. The result is a time-ordered set of histograms which plot frequency vs. amplitude, where each code signal in the bandpass of the receiver shows up as a peak. Using conventional FFT analysis, these peaks are not necessarily sharp, but by using the Linear Prediction technique the signals show up as very sharp spikes. The set of histograms produced can then be analyzed further to determine where the marks and spaces fall. Appendix C shows some encouraging preliminary results produced by this technique.

b. Code Transcription

As as result of the early efforts in Morse transcription which led to the conclusion that any transcriber which makes binary decisions on thresholds will show poor results (and which was earlier articulated in the section of this report on the commercially available transcribers), a new technique was developed that abandons the notion of thresholds and instead uses the notion of floating probability distributions. The notion itself is not dissimilar from the "confidence value" ideas articulated in the previous two studies, but the implementation is. Specifically, instead of allowing the confidence value to go to 0 at a threshold setting as was the case in the MIT project, this technique assumes there is no such threshold but that there is some non-zero probability (even if very small) that a given mark could be either a dit or a dah and similarly that a given space has a non-zero probability that it could be an element, letter, or word space.

To calculate these probabilities, histograms are maintained which represent the frequency with which each type of mark and space have appeared in the transcriptions of this particular sender. These histograms represent the probability distributions of each type of mark or space around some mean value, and they more fully reflect a particular operator's characteristics as the amount of code received from that operator increases. Because of the natural tendency of an operator to change speed over time, the means themselves change. In all cases, the histograms (i.e. the probability distributions) are processed relative to the means, so that as the operator's speed

changes, this past history about that operator is still meaningful in the changed context.

The combination of histograms and means represents a model of the operator's sending characteristics at any particular point in time. As time changes, so too does this model. Because the model consists of both short-term (the means) and long term (the histograms) components, several interesting practical features result. For example, when an operator suddenly speeds up or slows down, the short-term means change. By comparing the current means with the historical means, such speed changes can be detected and compensated for. One such compensation that will happen automatically is that all of the long-term portions of the model are immediately adjusted for the new means. This may not be desirable however, if the operator's sending characteristics change drastically when the speed changes. Therefore, when such changes are detected, a new set of histograms can be invoked so that the altered sending characteristics are taken into account.

While the ability to capture the sending characteristics of an operator by use of this sort of model is important, it is even more important to be able to make good use of the confidence values that result. This is done by constructing a lattice based on the Morse code character combinations. This lattice contains individual and cumulative probabilities for each of the possible letter combinations. As each new mark or space is added to the lattice, its path through the lattice alters the cumulative probability of the path taken by some number of the past marks and spaces. When the cumulative

probability at some point in the lattice either does not change at all or changes by a very small amount, the lattice at that point is considered to be stable. In the current implementation, when a letter space or word space is observed to be stable, the characters that have not been output up to that point are printed on the terminal. (It is interesting to note that this technique produces a lag in typing almost identical to that produced by a human when copying Morse code.)

This transcriber does a remarkably good job -- better, in fact, than any pure transcriber (i.e.: one without word-matching or other post-processing) currently known to this author. It runs in real-time, copying signals off of the air, transcribing them character-for-character. It has been tested with code sent by straight keys, bugs, and electronic keyers on Ham Radio and Coast Guard channels, all with good results. It is not subject to the typical errors of the old style transcribers such as stringing groups of E's (dits) and T's (dahs) together or attempting to run two letters into one.

It is still not error-free, however, since it is prone to substituting letter spaces for word spaces and vice-versa. While there is no way to know for sure, we believe that this is about the best that can be achieved using a pure transcriber; i.e., that the li[illegible]as been reached with what can be done using just timing data and the Morse character alphabet, without additional world knowledge.

3. <u>Transcription of Coast Guard Signals</u>

The techniques reported above were used to transcribe signals obtained from Coast Guard frequencies. These signals were obtained through tape recordings made at a Coast Guard communications station of a live communications position and by passive monitoring of Coast Guard communications channels using a radio receiver at FEL Industries.

A total of about twenty hours of air time was transcribed. This figure is misleading however in that about 90% of that air time was silence. Therefore, only about two hours of actual Morse code was processed. This is still a large number of signals and operators however, and represents a good cross-section of what a future transcriber must deal with.

a. Demodulation

The signals recorded on tape at the Coast Guard communications station presented several difficulties for the demodulation components of the system. When subjected to the envelope detector, the signals did not trigger it properly at all. The reason for this is that the bandwidth of the receiver was set so narrowly that a "ringing" would be produced when noise and static pulses appeared. This ringing was often stronger than the signal itself, that no useful data could be obtained. This problem did not occur with signals obtained directly off-the-air since it was possible to adjust the receiver so that no such ringing occurred. In this case, the results were better, but still disappointing, as previously described in the section on the commercially available transcribers.

The phase-locked loop technique also had trouble with the tape-recorded signals and not with off-the-air signals because of the receiver setting used by the Coast Guard operator. Specifically, many of the signals appeared as an audio frequency which was lower than what the PLL system was designed for. This, however was easier to correct by changing the PLL circuitry to accommodate the lower frequency. Even then, though, the data produced was not as good as at the higher frequency, because the PLL took more time to synchronize on marks (since its synchronization is based on the number of cycles rather than real time), resulting in somewhat distorted timing data.

b. Transcription

When the acceptable demodulated signals were submitted to the transcription phase, approximately 20% produced no meaningful output, approximately 20% could be read and understood with no difficulty, and the remaining 60% produced transcripts which could be interpreted as to their general meaning, but where the confidence that could be placed on the details varied a great deal.

The unreadable 20% was almost universally due to very poor Morse code sending on the part of the operator. However, some of it was also due to the fact that the signal would fade out or that the transmission was of such short duration that the transcriber did not get enough code on which to synchronize. This later problem is because a very elementary technique is used to do the initial synchronization. When it works, it works perfectly and when it fails, it completely fails. This technique was used in order to get the

transcriber operating quickly and does not pose an essential limitation on its usefulness since there are several more complex techniques that are known to produce good results.

The highly readable 20% was produced by good operators with reasonably stable (but by no means perfect) signals. The 60% remaining signals spanned the distance between the two extremes both in terms of quality of operator and the quality of the demodulated signal.

The upper 80% of the signals were all copiable by an experienced non-Coast Guard Ham Morse operator, but some of those in the lower portion of the 60% presented difficulty. No attempt was made to gather statistics on error rates, but it is certain that the operator made far fewer errors than did the transcriber.

On the worst 20% of the signals, the human operator also could not interpret their meaning. They appeared to not be Morse code at all, but meaningless sequences of marks and spaces. However, since we knew that communications were being carried out, the operator eventually was able to discern patterns and interpret their meaning. However, it was never possible to say with any degree of certainty that the interpretation thus obtained was correct. What did become apparent, though, is that by copying this style of code, one can become attuned to its idiosyncrasies and eventually interpret much of it. That interpretation, though, appears to be based not so much on the marks and spaces actually sent, but on the style of sending and context within which the transmissions take place. It is conjectured that this is what the more experienced Coast Guard operators do, and

that this is at the root of the apparent "guessing" mentioned in Section II.E of this report.

D. Conclusion

All of the projects reviewed here present useful techniques for application to the Coast Guard Morse code problem, but none can be used as-is without modification and further development. It is reasonably clear that some sort of confidence value technique should be employed, probably during and between all phases of the process. More work is still necessary on the demodulation components. No more theoretical work is necessary on the pure transcription components. A great deal of work is required on the "world knowledge" components since that is what appears necessary in order to successfully interpret most (i.e.: the lower quality 80%) of the Morse transmissions.

This conclusion, while initially discouraging, does not necessarily mean that a solution to the problem is so far removed as to be impractical. The history of Morse transcription development efforts is that they have not been oriented toward the overall problem to be solved, but rather have attacked particular sub-pieces that may or may not be representative of the real issues involved. Many have been undertaken by researchers that did not understand Morse or that knew the dot-dash character combinations, but have never copied a signal off the air or operated a transmitter. Such persons could not conceivably be expected to have the insights necessary to put together a useful Morse system.

In addition, the problem is generally viewed as being "simple": "After all, it is only a series of dots and dashes. Certainly a computer can interpret <u>that</u>!" For this reason, it has not attracted widespread attention of knowledgeable workers, and organizations have not given it enough priority to fund any but small projects, thus further restricting the level of interest that is generated in the problem.

In all likelihood, the problem will remain unsolved until a coordinated project is undertaken which has as its goal the building of a complete operational system. Such a development program will not be cheap, nor is it guaranteed to succeed, but it is clear that until it is undertaken, there will be no significant breakthrough in the Morse interpretation problem. It is on the assumption that such a project may be undertaken by the Coast Guard, that the next chapter of this report, consisting of an overall design of an operational system, is presented.

VII. DESIGN OF AN AUTOMATIC MORSE CODE TRANSCRIPTION SYSTEM

In this chapter, some ideas are presented for developing a complete system which will be capable of automatically interpreting Morse code transmissions. The purpose here is not to give an in-depth technical or hardware design, but rather to sketch the components that will be necessary in such a system and how they will interact with one another. In those areas where extensive development has already taken place, specific techniques will be recommended. The system envisioned includes the following components:

The Extraction Components:

Receiver Control
Signal Processing
Signal Separation
Code Transcription

The Understanding Components:

Word Matching
Syntactic Analysis
Semantic Understanding
Pragmatic Interpretation

The Knowledge Components:

Long-term Memory
Session Memory
Exchange Memory

The Executive Components:

Control
Intervention
Analysis
Logging

Each of these components is discussed in detail in the section which follow.

A. The Extraction Components

It is the responsibility of these components to do all of what has so far been referred to as "demodulation" and "transcription". Essentially, these components extract the raw data (i.e.: an initial estimate of the letters represented in the signal) that will be used by later components. While there is still some development work which needs to be done in the Signal Processing area, it is relatively straightforward. Therefore, there is low risk that these components can be successfully integrated in a short period of time.

1. Receiver Control

It is the responsibility of this component to cause necessary adjustments to be made to the radio receiver as prescribed by other components.. It must quickly respond to commands which direct it to do such things as change frequency, adjust gains, alter the BPO, or insert filters. While doing this, it must monitor certain other things over which it has semi-autonomous control. For instance, changing frequency may require that a preselector be tuned. This involves simultaneously making an adjustment and monitoring the signal level until the maximum level is produced. But this level may be so much as to overdrive the equipment on the audio output, so the audio gain will have to be simultaneously reduced. The use of a digitally controlled receiver should make this component relatively easy to

implement. While the current receivers used by the Coast Guard have not been analyzed in this regard, they are capable of operation via a control link in a remote location. Therefore, if this link is not already digital, it probably would not be difficult to build a digital interface to it.

2. Signal Processing

The Signal Processing component converts the analog signals of the radio receiver into digital signals that can be processed by the computer. There are two techniques that are likely to be successful in the Signal Processing area, and both should be pursued. They are modified versions of the Line r Prediction and Phase-Locked Loop techniques discussed in Section VI.C.2.a.

a. Linear Prediction

The results of the Linear Prediction technique as shown in Appendix C are quite impressive. The specific program used to generate the results shown here was designed to model human speech, and appears capable of producing the required Morse code timing information under even the worst signal, noise, interference, and static conditions. More test results should be obtained, though, in order to verify this conclusion.

In the event that the current Linear Prediction programs will not produce the desired results, an improvement upon them is possible. Specifically, since the current programs are designed to model human speech, assumptions have been made which do not apply to Morse code.

By changing the model to reflect the characteristics of Morse code, it is felt that the already excellent results can be made even better. Specifically, by tuning the model so that it is expecting sine waves rather than the more complex speech wave forms, and by allowing it to dynamically adjust to the number of signals currently being received, improvements in weak signal and adjacent signal performance can be expected.

The current programs use a large computer to do their processing, and the cost of such a computer would be prohibitive for the eventual transcription system. Fortunately, the advent of the new 32-bit micro-computers with auxiliary arithmetic processors should allow this sort of processing to be performed economically. Once the programs are proven to be successful on the large machines, they should be streamlined and made operational on the micro-computer.

b. Multiple Phase-Locked Loops

One of the nice features of the Linear Prediction technique is that it can analyze a relatively wide band of signals all at once. For example, the diagrams in the appendix show all signals that appeared in a 5 kHz audio bandwidth. Since each of these signals shows up as a separate peak, it is possible to track (and copy) all of them at the same time. In addition, it eliminates the need to adjust the frequency of the receiver for each incoming signal and gives valuable information about general signal conditions which can be taken into account when eventually decoding the message. Certainly, the phase-locked loop (PLL) technique described thus far does not have

these desirable characteristics, but there is an expansion of the technique that shows promise.

By using many PLLs (possibly as many as 100), each one sharply tuned to a slightly different frequency within the range of the receiver audio output, it should be possible to achieve similar results as with the Linear Prediction technique. Since the PLLs will be sharply tuned, weak signals can be detected. By overlapping the frequency ranges of adjacent PLLs, noise can be detected and rejected and different signals will appear on the outputs of different sets of PLLs. Since the PLLs themselves can be digitally controlled, it will be possible to dynamically re-tune selected ones if, for example, increased sensitivity or selectivity is needed in order to decode a particularly important signal.

The cost of this approach is likely to be well within the range of a practical transcription system. The PLL's are inexpensive standard chips, as is the accompanying circuitry. Therefore, once designed and working, the cost of each additional unit would be low, especially if many are constructed at the same time.

3. Signal Separation

There may be many signals present in the bandpass of the receiver and all will be represented in the histograms output by the Linear Prediction technique or in the logic output of the multiple phase locked loop design. It is the responsibility of the Signal Separation component to analyze these outputs over time and to determine the mark/space timings of the desired signals. This requires more than

simply watching what happens at a particular frequency since receivers and transmitters drift, other signals temporarily block out the one being copied, fading causes the signal to go into the noise, and sudden frequency jumps might occur (e.g.: by an operator accidentally knocking against a transmitter adjustment). Thus, this component must keep track of which signals are the ones being copied and which ones are of no interest. If nearby interference or fading causes the signal to temporarily vanish, it must record this fact along with the time intervals involved. If a signal that was not previously present appears, the signal separation component must not become confused, but must track it and report it to the other system components so that they can make a decision of whether to copy it or not.

The Signal Separation component must also be able to take commands which direct it to track signals different from the current set, or, if emergency or other conditions exist, to put most or all of its processing power into one particular signal. Another situation that requires taking commands from other components could occur, for instance, when a confusion results over two very nearby signals, but another component determines that what is being said doesn't make sense in the context of the current transmissions. In this case, forcing attention to the other signal would be necessary.

The Signal Separation component would be identical no matter which of the two Signal Processing techniques are employed, except that a different software interface would be required for each. Since both techniques would be implemented simultaneously during the development phase, both interfaces will also need to be built. Since

these are relatively simple interfaces, building both is quite practical.

4. Code Transcription

The method utilizing floating probability distributions outlined in Section VI.C.2.b should be used to transcribe the timing data output from the Signal Separation component. The output from the transcription will include tentative character strings, complete with their individual and collective confidence values. The major work required to implement this component involves writing better initial synchronization programs and implementation of all the programs on an inexpensive micro-computer instead of the mainframe computer on which they currently run.

B. The Understanding Components

1. Why Understanding?

Even with perfect transcription, we could not expect perfect output from the Extraction Components. This is, of course, because it didn't get perfect input. Words were probably misspelled, or signals faded and part of a word or sentence was missing, or perhaps even the wrong signal was temporarily copied. Thus, no Morse code system will be successful unless it has an understanding of the language and of the communication process being used. "Language" is being used here in a very general sense. For instance, if a station is sending 5-character code groups (a frequent way of sending data or encrypting text), then the language is quite simple and has only those grammar

rules that define the sign-on/sign-off sequence and the 5-character structure of the text. On the other hand, if the language is natural English, then the grammar rules are very complex, and large amounts of information about the world must be known in order to understand it.

The vocabulary of the radio operator consists almost entirely of abbreviations and special symbols as described in Section II.B.1 of this report. Except for the actual messages being transmitted (and even here there are many exceptions), most words are simply not real English words. Moreover, the grammar used to string these words together is much different from English grammar. In fact, full English sentences rarely occur, and the communication that takes place is a beautiful example of a pragmatically guided system.

Thus, the understanding components of our system must take into account not just what the words and grammar rules are, or what the stand-alone meaning of the sentences are, but they must constantly monitor <u>why</u> the sending operator has chosen to send a particular piece of information, and <u>what</u> he expects the receiving party to do with it. They must also be aware of <u>how</u> he sends it, because this has implications for how to interpret its meaning. For example, an operator may normally send his location as "QTH BOSTON", where "QTH" means "My location is". But if receiving conditions for the sending operator are poor, he is likely to send "QTH BOSTON-pause-BOSTON" because he believes that receiving conditions are likely to be just as poor at the other station. This tells us more than just what his location is; specifically, it tells us that he is having difficulty

receiving and that we should so notify the radio operator in order that he keeps his transmissions short and constantly verifies that the other operator is receiving him. Also, we don't want to misinterpret his location as BOSTON-BOSTON since it will be used in logging and subsequent decoding of the message.

2. Components of the Understander

In order to exhibit the sort of understanding described here, the system must have a knowledge of the vocabulary and grammar rules of the language in use, the meanings that result from using sentences of that language in various contexts, and the practical (rather than the literal) interpretation that those meanings imply. The sections which follow discuss each of these four aspects of the understanding process. They assume that the language is of a complexity at least equal to that used in the Morse message handling environment. For a simpler language, such as when code groups are sent, each component would be significantly simpler than implied by the discussion.

Note that conceptually it might seem reasonable to take a transcribed string, subject it to a program that figures out what words are contained in it, then determine the sentence structure based on some set of grammar rules, then figure out what the resulting sentence means, and finally figure out its practical implications. In some limited contexts, this simple linear processing approach might work, but in general it will not. Thus, even though the individual Understanding components are discussed in sequential order, the actual implementation will result in very complex interactions taking place among them. Section VII.D.1 discusses this concept in more detail.

a. <u>Word Matching</u>

It is the responsibility of this component to hypothesize the existence of a word at specified places in the signal. It will use several techniques to do this depending on information specified by other components of the system, including dictionary lookup, word construction and verification rules, and the more complex (but beneficial) technique of run-length sequences described in Section VI.B.2 of this report. For example, if the string

"WCC WCC DE"

has been received, the other components would inform the Word Matcher that the next "word" is likely to be another call sign. (The word "likely" is used here since radio operators do strange things, and there is no such concept as "always". Therefore, the entire system will be built around likelihoods, thus enabling it to handle even the strange cases.) Knowing this, the Word Matcher will use a set of verification rules to attempt to find a call sign at the specified place in the signal. Associated with the character string found will be a confidence value that the code is actually a call sign, and both pieces of information will be reported to the other components. A similar sort of process will exist for other sets of words such as names, numbers, locations, type of ship, etc. In addition to these "rule experts", a dictionary will exist which is interrogated whenever words fitting a more general context are required. Again, however, the interrogation process will not be a simple word look-up, but will be guided by what the other components of the system believe to be likely in the current context.

b. Syntactic Analysis

Syntax refers to the way the words of a language are strung together to form sentences. For instance, in the example above, it is known that the language of radio operators contains a grammar rule that says that the way to transfer communication from one party to another is to send the receiving party's call sign, followed by the word "DE" (French for "from"), followed by the sending party's call sign. This is the information that the Syntactic Analysis component would use to give the Word Matcher the advice that the next word is likely to be a call sign. Similar grammar rules are to be built to handle the many other situations that arise, and the complexity of these rules gets greater as the language tends toward natural English.

The English language grammar used in the work reported in Section VI.B.3 is probably too limited to be of great value in a full-fledged Morse system, and in any case a new "Radio Operator Grammar" would have to be developed. Such development requires a great deal of effort and sophisticated computational techniques. Fortunately, much research has gone into this problem over the past ten years, and some natural language understanding systems have successfully been built. Which of these techniques would be most appropriate in the Morse domain is one of the first things that should be examined when the project is undertaken.

c. Semantic Understanding

Grammar rules as described above only indicate the structure that sentences of a language may take, but they have only supplementary

value in determining what the sentence means. For instance, the strings "NMN DE SJCT", "VCP DE WMH", and "W1ABC DE NSS" are identical from the point of view of the Syntactic Analysis component, however, they have quite different meanings. The first string represents the "normal" case where a land-based and a ship-based operator are communicating, and nothing very interesting is implied; the second case is more interesting because two land-based operators one talking to each other, implying a somewhat unusual situation; and the third case is very interesting since a Ham radio station and a U.S. Military station are communicating -- a rare but occasional event.

Thus, it is necessary to incorporate additional information into the system that will pay attention to the semantics of individual words, phrases, complete sentences, and series of sentences. Furthermore, it often happens that code is sent that does not represent a grammatically correct sentence, yet which can nevertheless be understood by the receiving operator. The handling of such code will largely be the responsibility of the semantic understanding component.

As with Syntactic Analysis, a great deal of work has taken place in this area. Furthermore, the two types of analysis are generally believed to both be necessary in order for either to properly perform their functions. They have been discussed separately here for exposition purposes, but will actually be implemented as one closely-coupled sub-system.

d. Pragmatic Interpretation

If an operator sends "NMF DE AXGD", in all likelihood that operator is on a ship at sea. However, if the previous sentence was "QTH BOSTON" ("My location is Boston"), then some doubt is placed on that interpretation, especially if we realize the NMF is the Boston communications station. In this case, the literal interpretation of the call sign exchange must be abandoned, and a more pragmatic interpretation is made based on information which is known externally to the specific details of the transmission. Since on-the-air operators often deviate from standard procedures either accidentally or on purpose, this ability to recognize inconsistencies is essential to the understanding processes.

C. The Knowledge Components

When building a system of the complexity of this one, several issues arise as to the proper structuring of the data and of the processes that manipulate that data. This section presents concepts related to the organization of the data contained in the system, while the next one concentrates on how the various processes of the system will fit together to accomplish a specific goal or set of goals.

1. Separation of Data From Processes

A problem which often occurs with systems is that once built for a particular application, it is a major effort to modify them even for only slightly different applications. There are several reasons for this, of course, but one of the major ones is that too much

information about the problem domain is built directly into the computer code. Thus, to go to even a slightly different domain can require major changes to that code.

To avoid this problem, the system must be designed to isolate the data from the processes as much as possible. For example, the Code Transcription component requires a knowledge of the Morse code alphabet. It is very tempting to build this knowledge directly into the program that uses it. However, if this is done, it would be a reprogramming task to modify the system to include special symbols that may have been forgotten, alternate codings for the same symbol (there are two different versions of the double quote (") sign), cut numbers (where one DAH is used to signify a string of DAH's in order to speed transmissions of long groups of numbers), or the special codes used for the Russian alphabet.

This concept is to be carried throughout the system. Some cases, such as the dictionary mentioned in the section on Word Matching, will be as straightforward as that described above. Others, such as information about the sending characteristics of a particular operator (See Section VI.C.2.b.) will be constructed dynamically by the system and automatically saved when another operator starts sending. When the original operator resumes sending, the data relating to him will be retrieved by the system and processing will continue without the need to resynchronize on his code. Thus, a change of context will take place rapidly by merely interchanging two or more data files.

2. Knowledge Bases

Throughout the discussions of each component of the system, the existence of certain types of data has been implicitly assumed or explicitly stated. In this section, three types of data bases are discussed which are necessary to support the various components. Naturally, many other data structures will exist, but these three are discussed to give a feel for the types of knowledge-base issues that arise.

a. Long-Term Memory

The data contained in long-term memory is of a global nature not necessarily relating to a specific communication. For example, it is necessary to have a basic knowledge of geography so that correct decisions can be made as to the intent of the various operators. Such information is mostly static in nature, but situations may arise where new information must be dynamically added.

b. Session Memory

There are many items of information that are obtained during the course of a communications session with a particular station. Some of these, such as its location and the name of the ship will be used several times during the session and will eventually be transferred to the Logging component (see Section VII.D.4.). Others, such as the number of messages the station has to transmit and where they are to go, are not important enough to store permanently, but are vital during the particular session. All of this information will be

stored in Session Memory while the session is in progress. All such information not transferred to long-term memory or logged will be lost as soon as a session begins with another station.

c. Exchange Memory

A session usually consists of several exchanges between each station. All information will originally appear in Exchange Memory and that which is relevant to the entire session will be transferred to Session Memory. The primary purpose of Exchange Memory will be to enable the understanding of the immediate transmission currently in progress. An important aspect of this is the resolution of ambiguities that occur. For instance, if one operator asks how many messages the other has for Alaska, and the other replies with a number, and then the original operator sends "HAWAII?", it is known that he is asking for the number of messages to go to Hawaii. If the short-term Exchange Memory didn't exist, it would be impossible to interpret this transmission.

D. The Executive Components

If all of the components discussed so far were complete and working perfectly, one crucial item would still be missing. That is, there must be a component that knows how to coordinate each of the others so that they all interact properly to achieve the overall system goals. This component is called "Control". The other three components discussed in this chapter satisfy human factor, research, and legal requirements.

1. Control

The Control component has the responsibility of knowing about the overall goals of the system and of coordinating the other components so that these goals are achieved. By keeping the specification of these goals separate from the other components, we achieve the ability to easily switch the global context in which the system operates in a manner similar to that discussed in Section VII.C.1.

Using the specified system goals, the Control component must activate the other components to accomplish these goals. It has been mentioned previously that each component provides advice to guide the others. In reality, each component provides advice to the Control component, and it is its job to determine which of this advice is most relevant to the current context, what advice should be provided to which components, how strongly this advice is to be heeded, in what order each of the components is to be activated, and how hard each component is to work on the problem before giving up.

Notice that the proper functioning of the Control component implies a lot about the structure of each of the other components. Specifically, no definite sequence of operations can be assumed to have been accomplished before a given component is activated. Instead, each component must be capable of working on any specified data structure which meets a general set of constraints, but which may be in various states of incompleteness or have inconsistencies within it. The programming of systems to detect and properly handle such irregularities of data has long been recognized as a sound system-building principle, but such systems are rarely implemented.

Since this system must operate in a real environment which is inherently ill-structured, imposing the type of constraints implied by the Control component is not an undue complexity, but rather forces us to implement the system the way it already must be implemented if it is to work.

2. Intervention

All of the discussion so far has implied that the system will be functioning completely on its own. This does not mean, however, that the system should ignore commands from humans, but rather that it must be able to successfully function without them. The intervention component provides the mechanism by which a human can, like all of the other components, provide advice to the system. As such, it will interface to Control in an identical manner. Usually, the only difference between the advice this component provides and that which the other ones give is that this advice is to be given greater weight. For instance, if the system has made an incorrect interpretation of a message, advice (perhaps more probably called an "order") which guides it to the correct interpretation, can be provided. Needless to say, the intervention component will be critical during the development stages, and in operation will provide the means through which humans remain in control of the system.

3. Analysis

It was mentioned above that the human could provide advice if an erroneous interpretation of a message is made. One of the functions

of the Analysis component is to provide the information that the human needs to determine how messages are being interpreted; and in general it analyzes what the system is doing. This component will also keep track of internal processing details so that if it is determined that an error has occurred, the information needed to analyze that error will be preserved. Finally, the Analysis component will maintain statistics about the overall operation of the system. This information will then be used to guide future improvements.

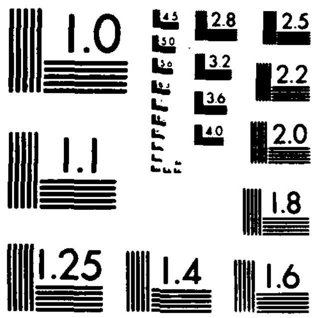
4. Logging

This component will keep detailed records about the operational aspects of the system. It will record what stations were received, on what frequency, its messages, and the time of receipt. It will record the name of the ship (if known), the station's location, details about its signal strength, unusual characteristics and anything else deemed important. Some of this information is required by law. The rest will be useful to the internal components of the system as well as to the station's operators.

AD-A138 947 PRELIMINARY ANALYSIS OF AUTOMATIC MORSE CODE TRANSCRIBERS FOR USE IN US C..(U) SPEECH COMMUNICATIONS RESEARCH LAB LOS ANGELES CA E W MERRIAM 1984 2/2

UNCLASSIFIED USCG-D-38-83 MDA904-82-C-0415 F/G 17/2.1 NL

END
DATE
FILMED
4 84
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

VIII. CONCLUSION

This report has analyzed the Coast Guard Morse code operating environment with respect to the possibility of automating the transcription function. Several existing systems and experimental projects have been reviewed, and a tentative design has been presented for a system to accomplish the task. It is hoped that this analysis and design provides a framework within which solid decisions can be made and developmental efforts based.

APPENDIX A

LIST OF COMMERCIAL TRANSCRIBERS EVALUATED

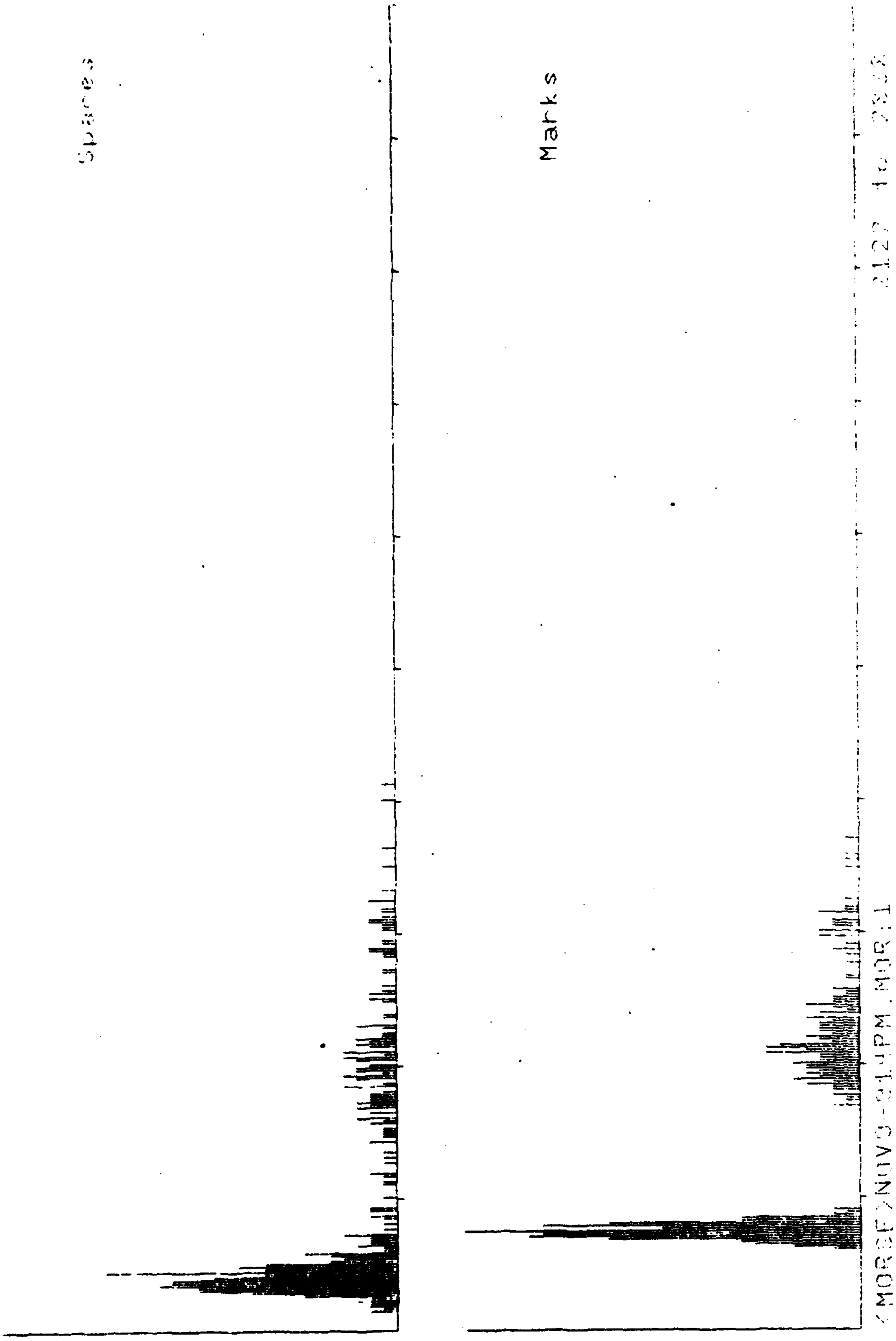
	Literature	Personal Discussions	Operating Manual	Evaluation Unit
Advanced Electronics Applications, MBA-RC	X	X	X	X
Crown Micro Products, ROM-116	X	X		
DGM Electronics, MVD-1000	X			
Digital Electronic Systems, INFO-TECH M-500	X	X		
R. L. Drake, Theta 7000E	X	X		
Dynamic Electronics, Inc, DE-200	X	X	X	X
HAL Communications Corp.	X			
Kantronics, Mini Reader	X	X	X	X
Kantronics, The Interface	X	X		
Macrotronics, Terminall	X	X	X	
Microcraft, Code*Star	X			
Microlog, ACT-1	X	X		
Robot Research, Inc., Robot 800	X			
Telecraft Labs, TAIMD	X		X	
Yaesu Electronics Corp, YR-901	X	X		

APPENDIX B: Examples of Mark-Space Histograms

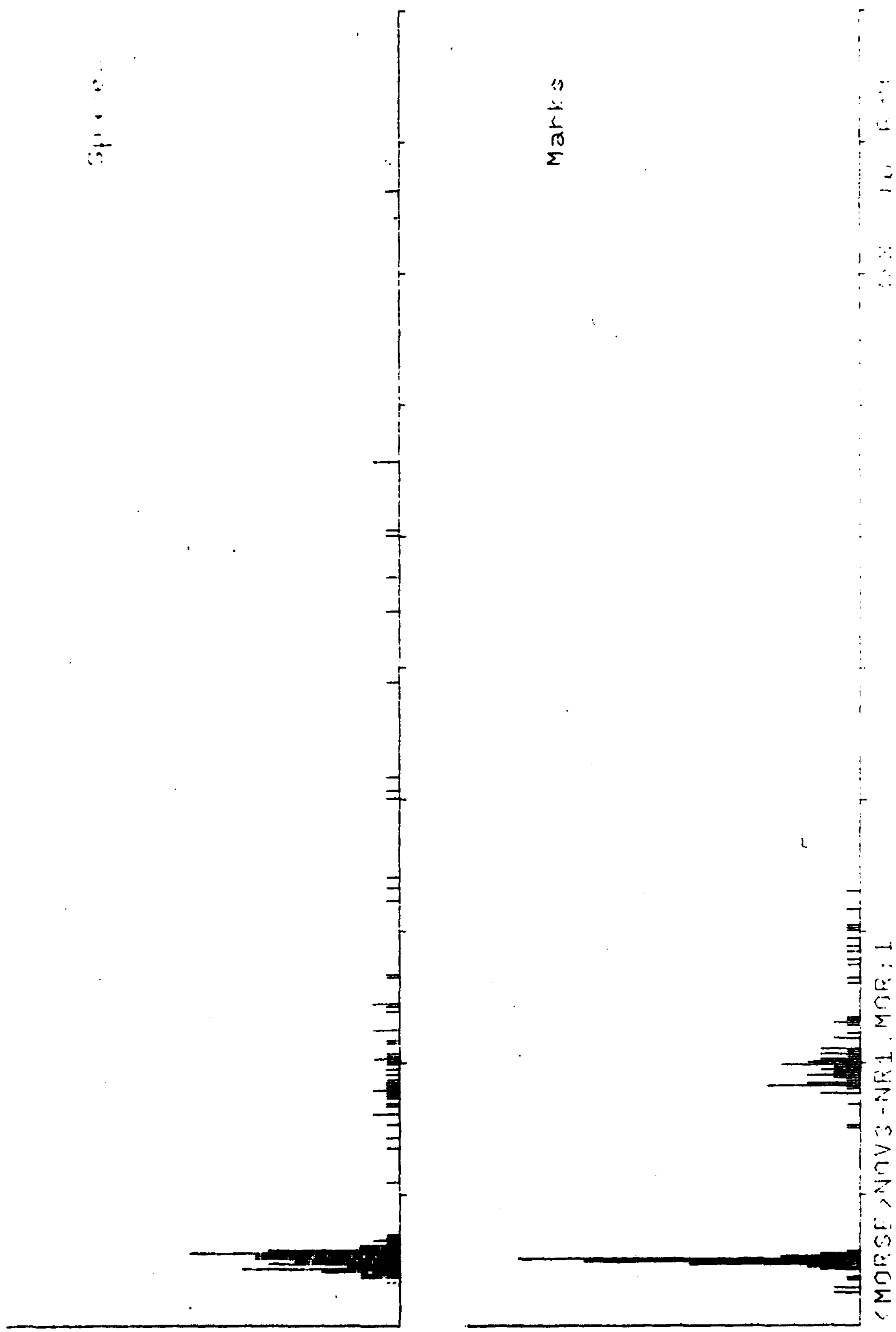
The histograms contained in this appendix represent the timing data which the Code Transcription component uses to decode a message. Each tick mark under the horizontal axis represents 50 milli-seconds. The length of each line vertically represents the number of items of the corresponding time duration received in the message. Notice that the histograms do not represent the probability distributions mentioned in the main text, but rather represent a composite of the raw data from which those distributions are derived.

These histograms clearly illustrate the difficulty of the problem that the Code Transcriber must solve. For example, it can be seen that in most cases the marks segregate into two fairly well-defined groups, obviously representing the DIT's and the DAH's. Depending on the operator, the spaces may or may not segregate into element and other spaces, and in no case is there a clear distinction between letter and word spaces. In the case of the last signal there is not even a clear separation of the DIT's and the DAH's.

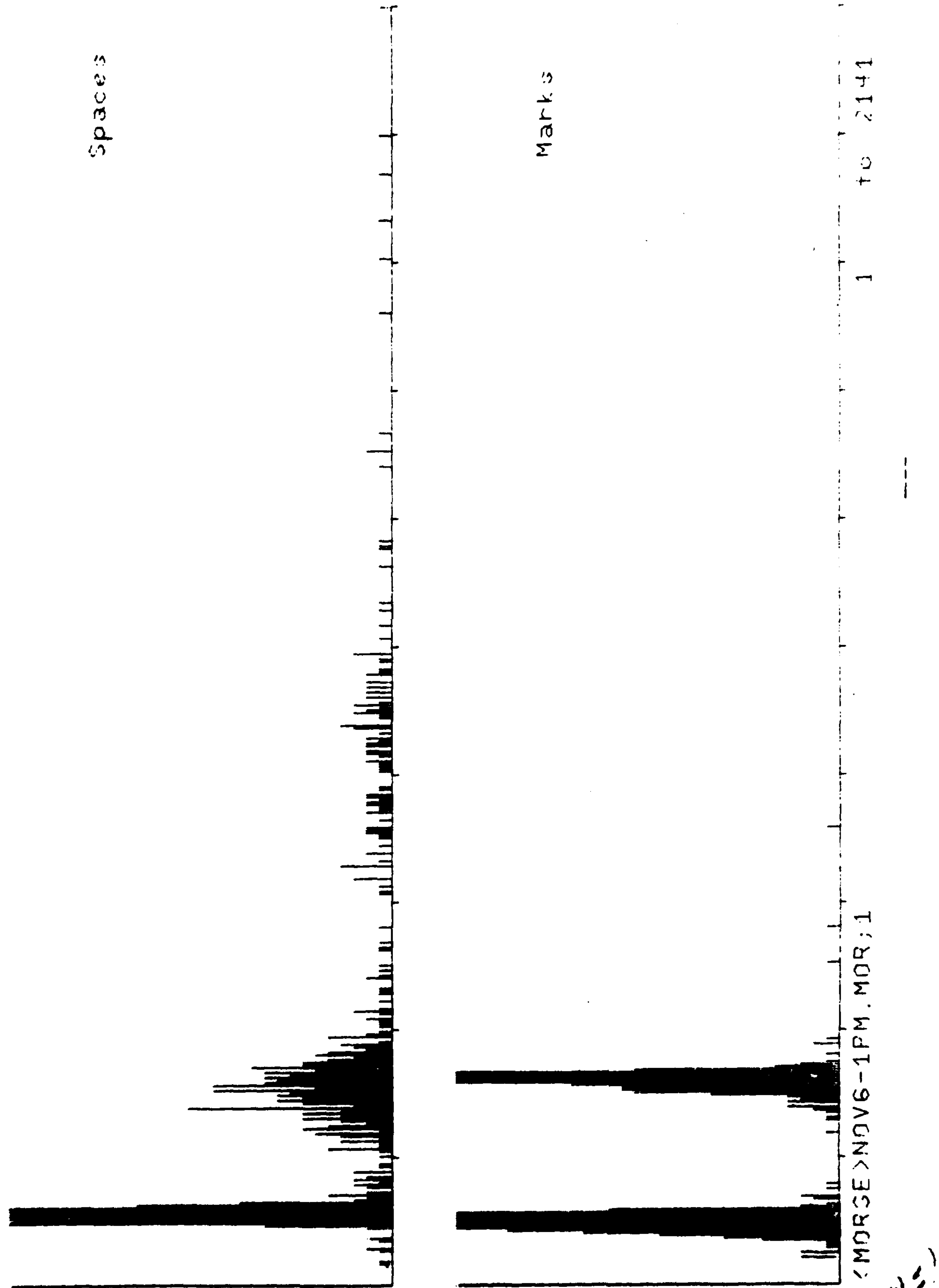
Coast Guard Morse Transcription - Preliminary Analysis
FEL Industries - January 1984



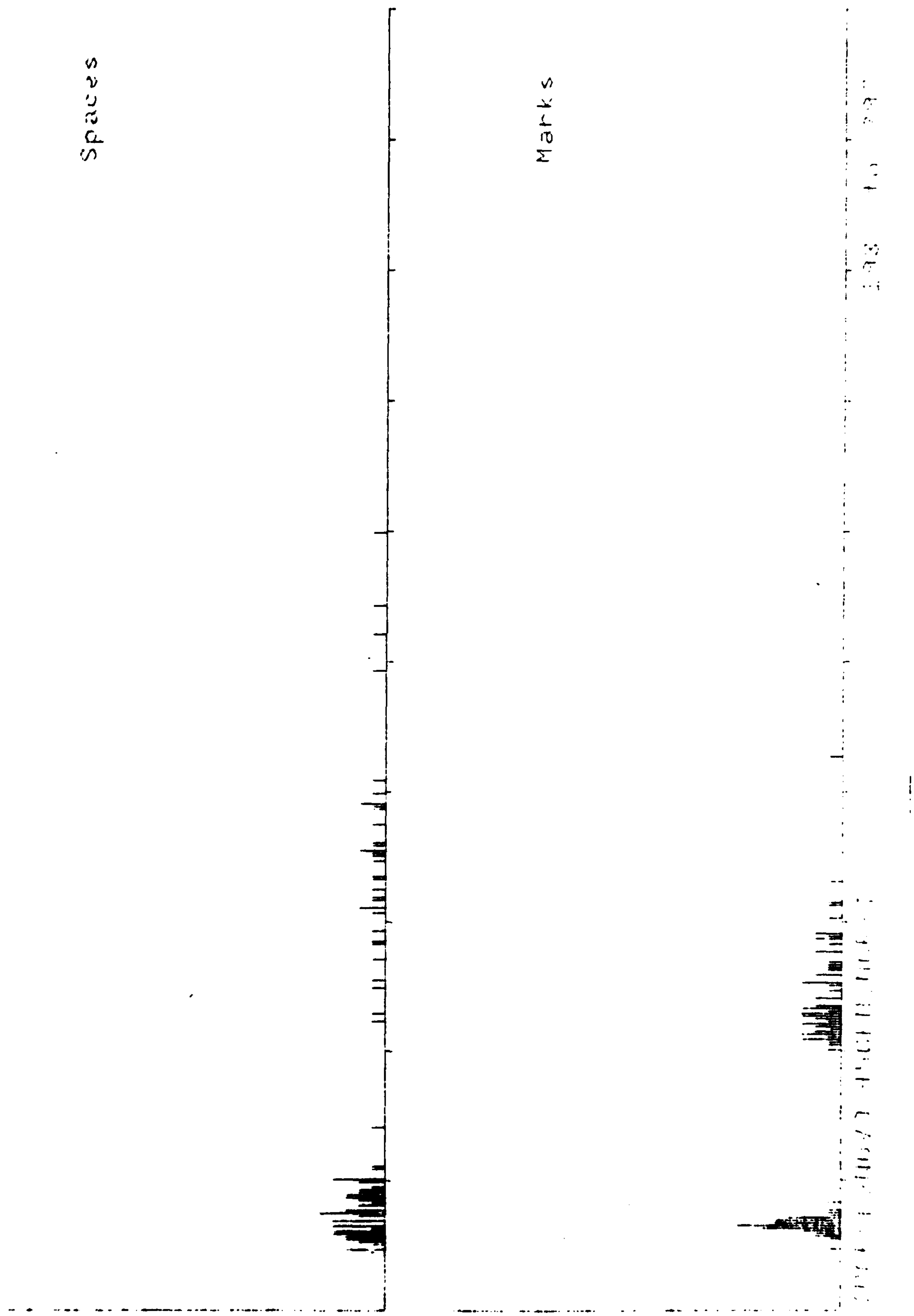
Coast Guard Morse Transcription - Preliminary Analysis
FEL Industries - January 1984



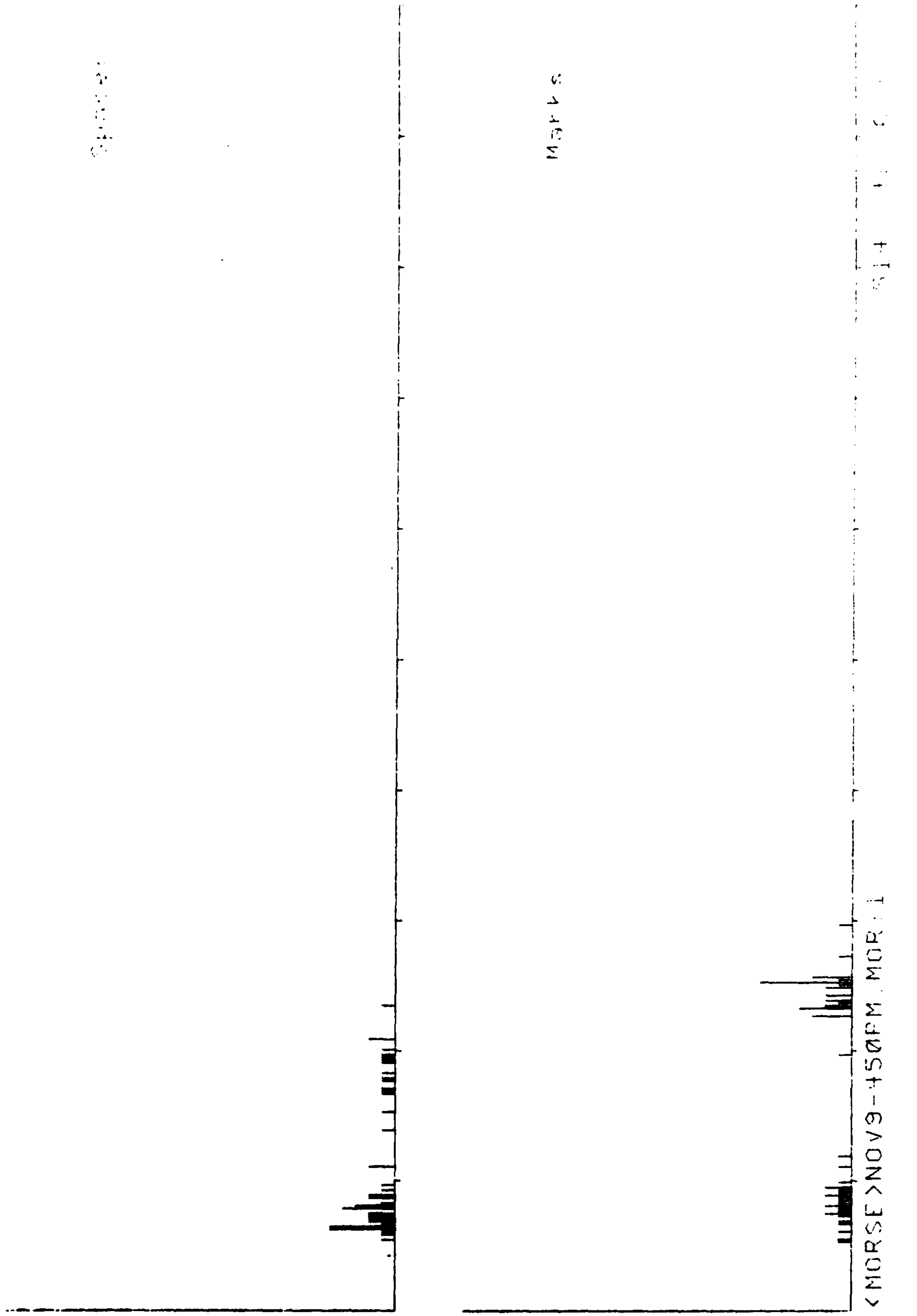
Coast Guard Morse Transcription - Preliminary Analysis
FEL Industries - January 1984



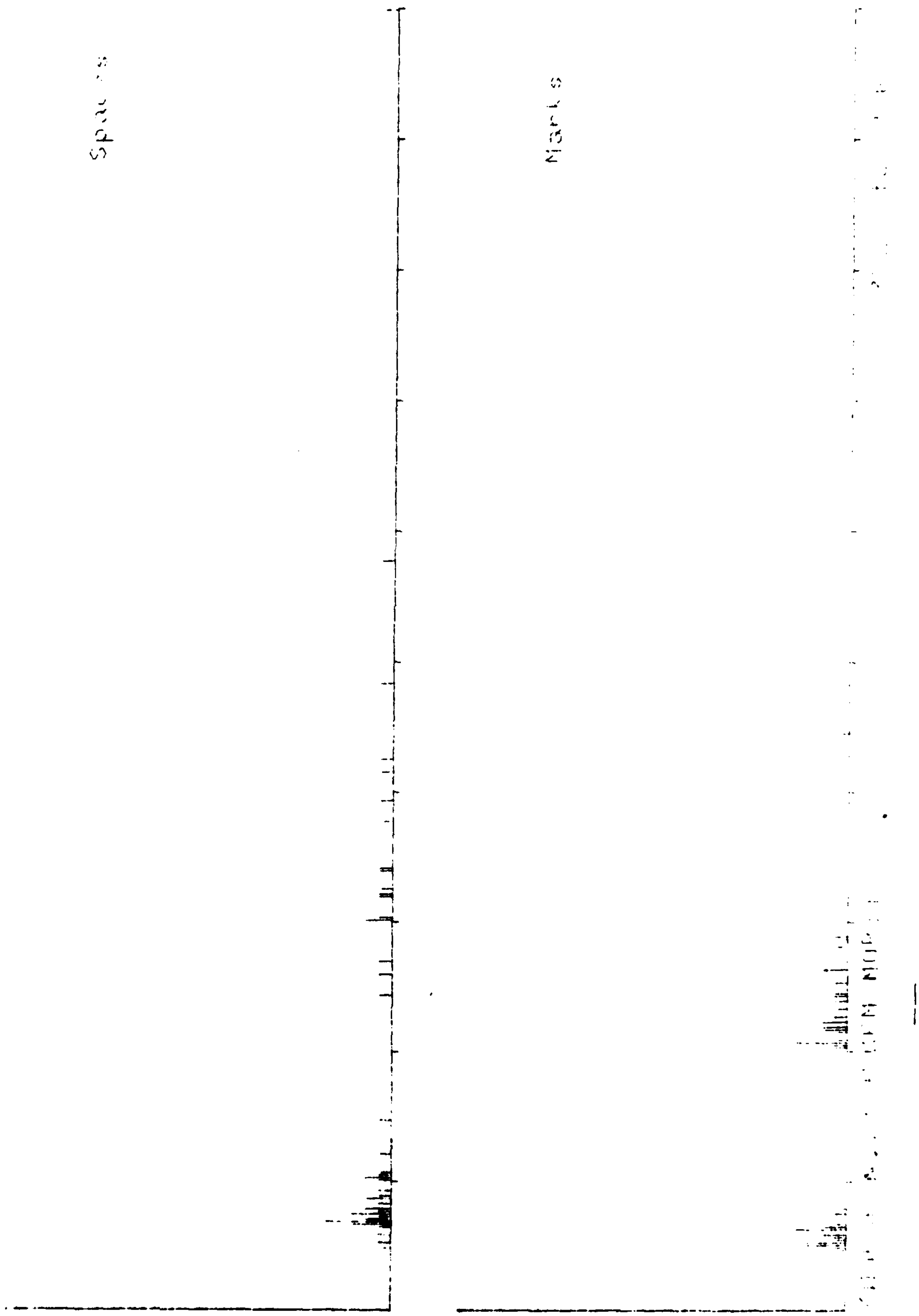
Coast Guard Morse Transcription - Preliminary Analysis
FEL Industries - January 1984



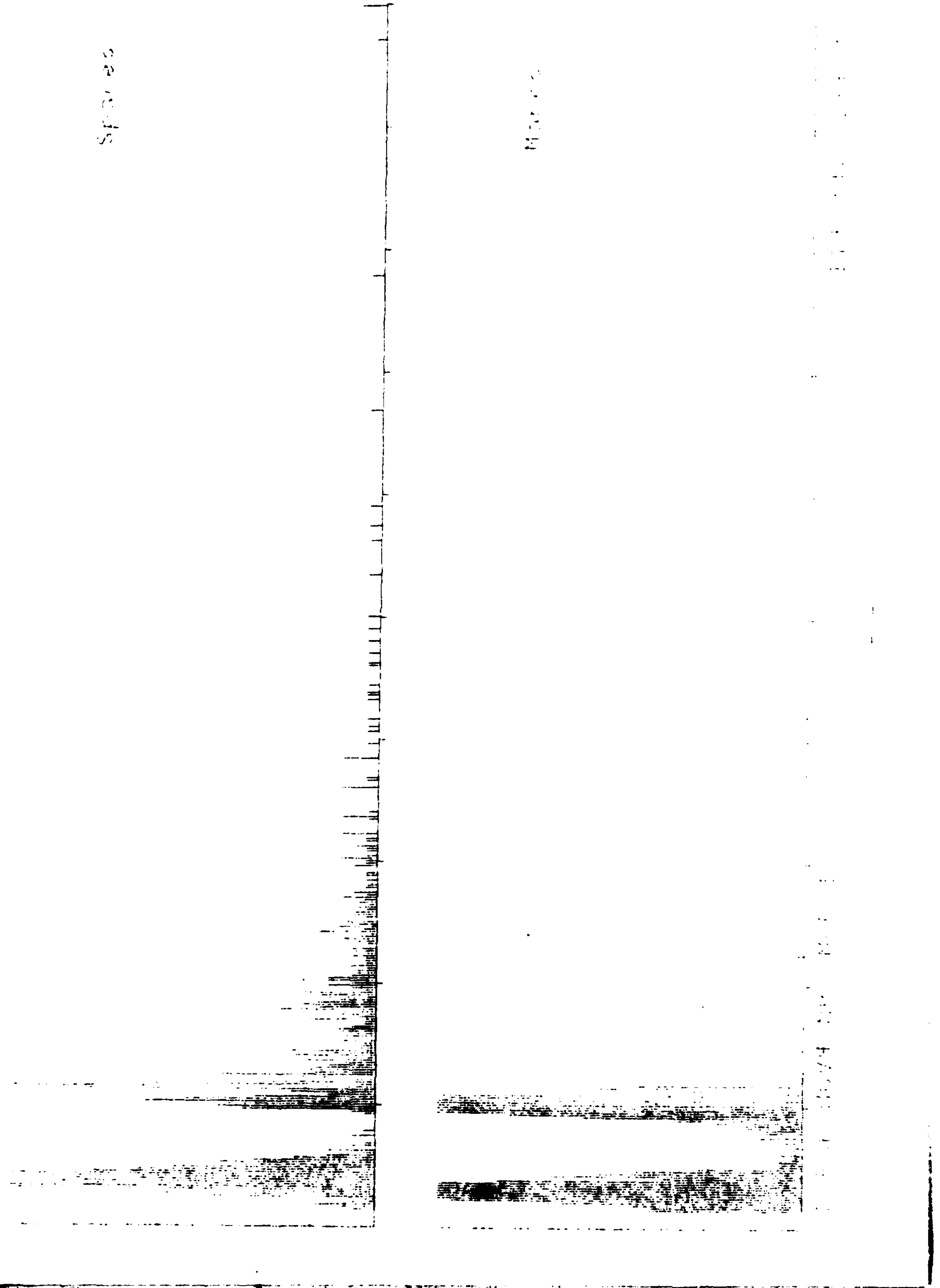
Coast Guard Morse Transcription - Preliminary Analysis
FEL Industries - January 1984



Coast Guard Morse Transcription - Preliminary Analysis
FEL Industries - January 1984



Coast Guard Morse Transcription - Preliminary Analysis
FEL Industries - January 1984



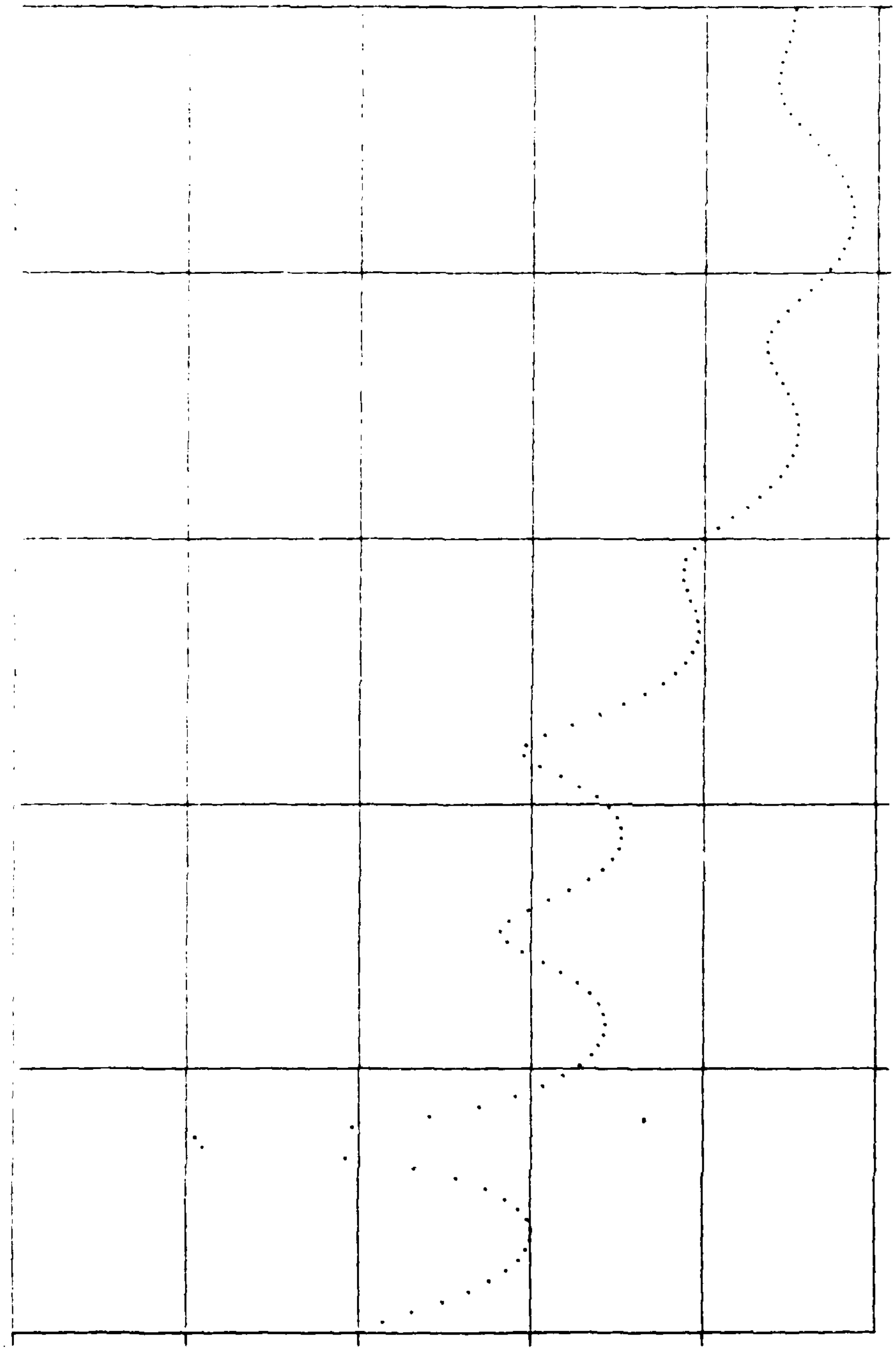
APPENDIX C: Sample Results of Digital Signal Processing

The diagrams in this appendix are included to illustrate our initial results in applying digital signal processing algorithms to the Morse code signal environment. Specifically, they represent a 60 milli-second period during one of the worst taped signal conditions we could find, including a great deal of interference, noise, and static. During this time period, the slow low-frequency signal was sending a mark. In the second diagram (labeled 570) the faster high-frequency signal begins to send a mark. This mark continues until the next-to-the last diagram (600). In the last diagram (610), only the low-frequency signal remains.

The vertical axis of all diagrams represent the amplitude of the signal on a logarithmic scale. The horizontal axis represents frequency and is divided into 1 kHz units. The wiggly line at the bottom represents the raw waveform, and the waveform from the left edge to the vertical line is the 20 milli-second section of waveform used to produce the analysis. The number is the time from the start of the signal (in milli-seconds) corresponding to the waveform at the left edge. Thus, an analysis was done every 10 ms on the next 20 ms of the waveform data.

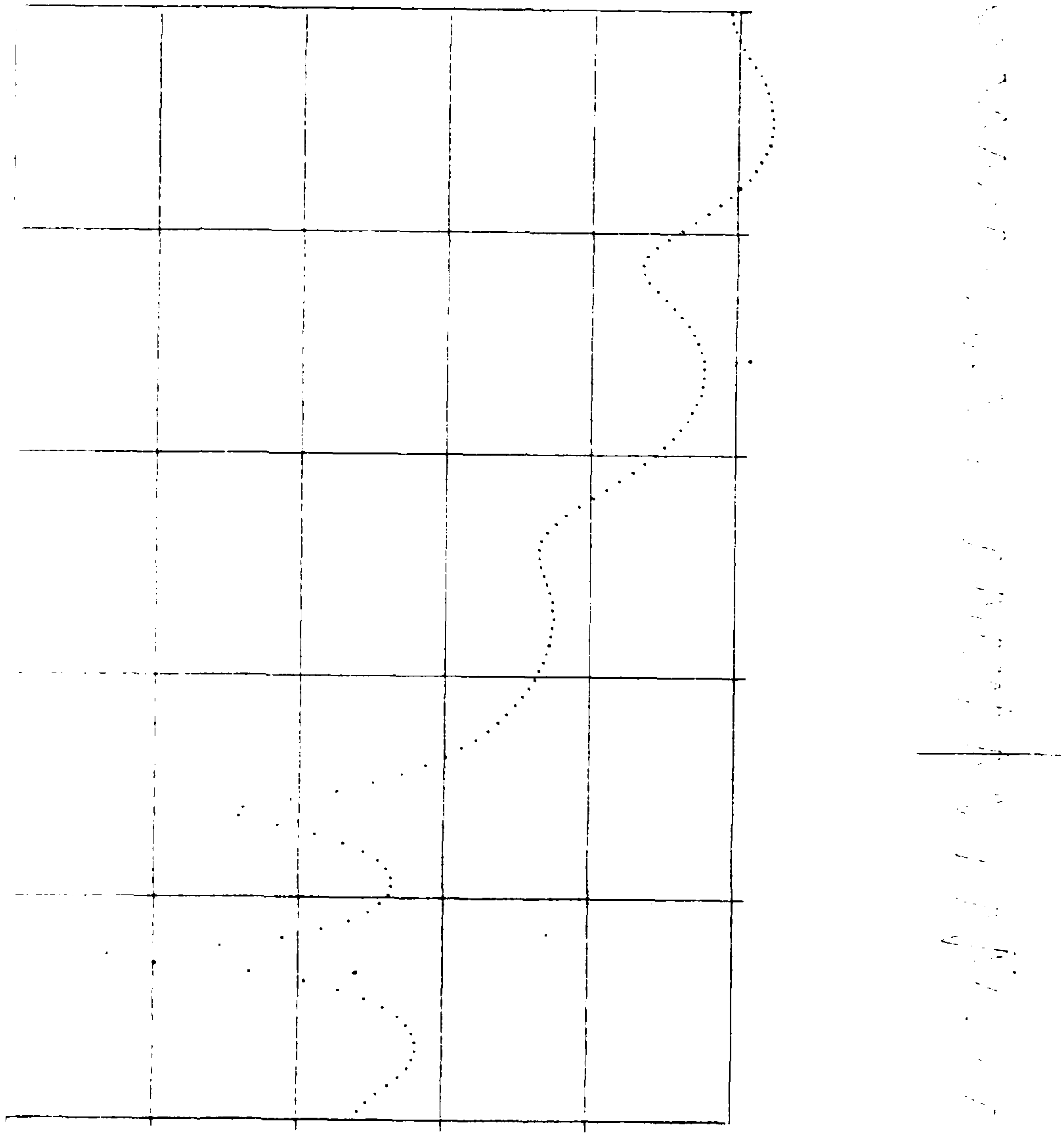
Peaks not mentioned above represent the ambient noise. In any one diagram these peaks could be confused with a signal peak, but by tracking from diagram-to-diagram (with the Signal Separation component outlined in the main text), this ambiguity is easily resolved.

Coast Guard Morse Transcription - Preliminary Analysis
FEL Industries - January 1984

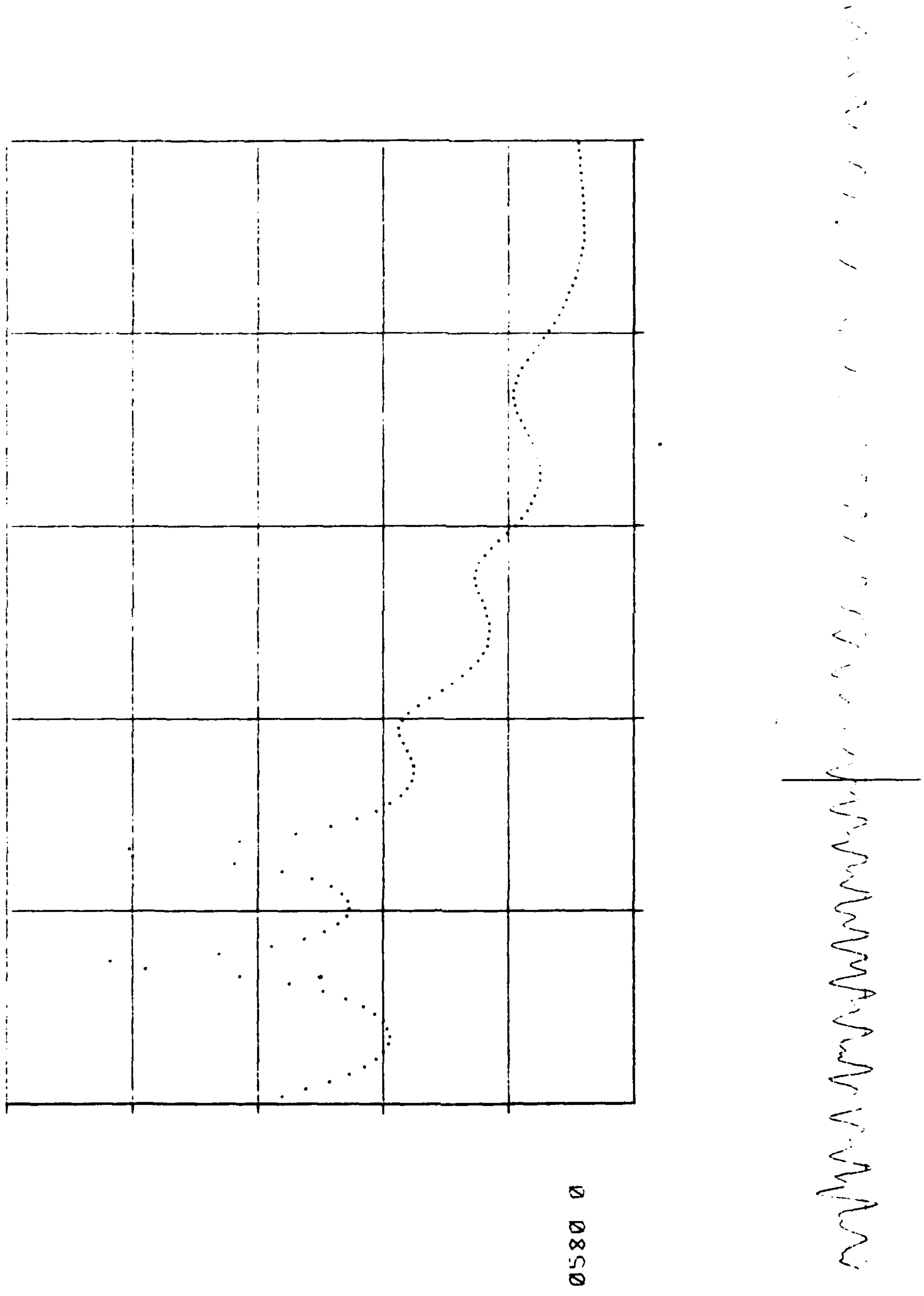


0560.0

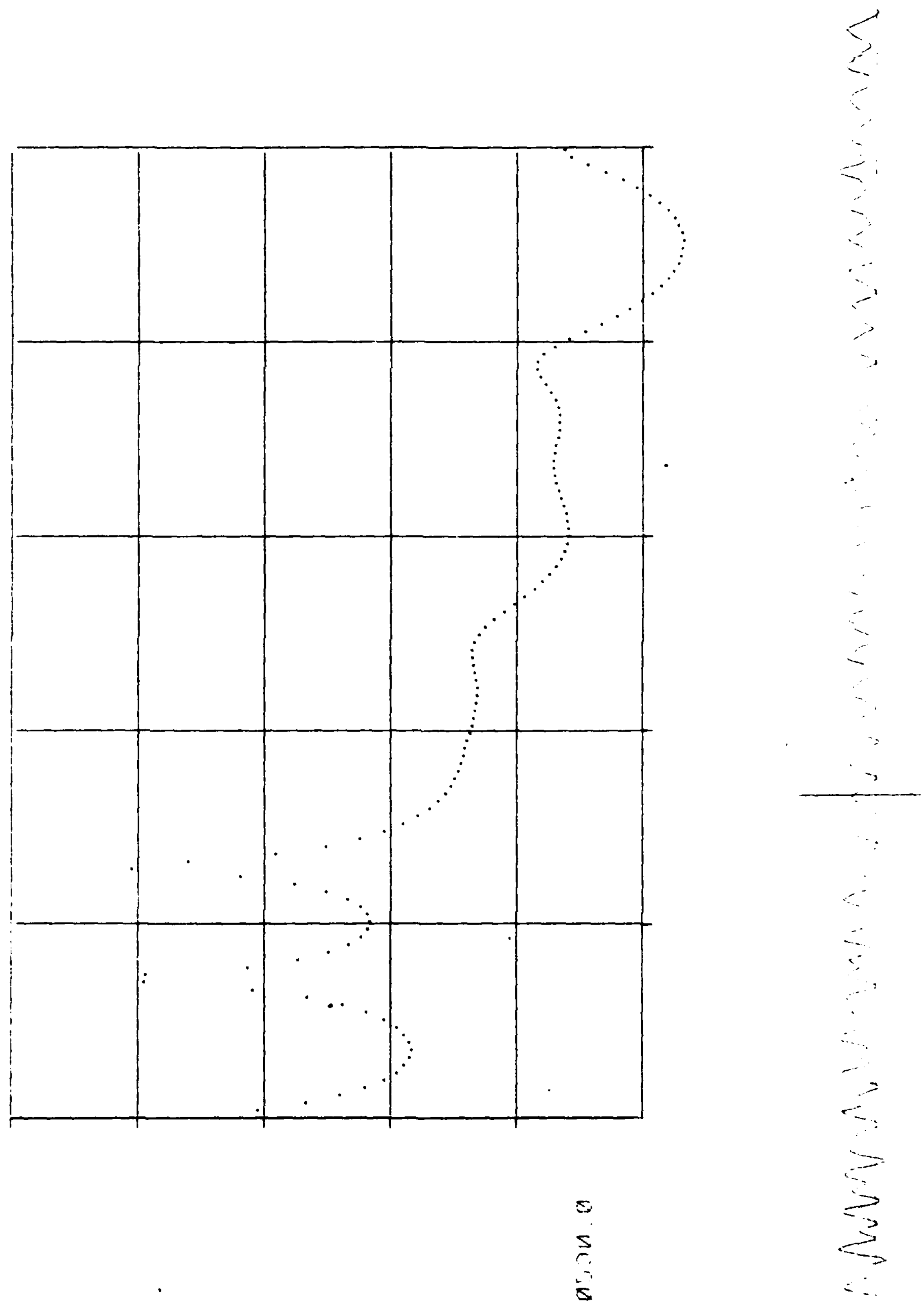
Coast Guard Morse Transcription - Preliminary Analysis
FEL Industries - January 1984



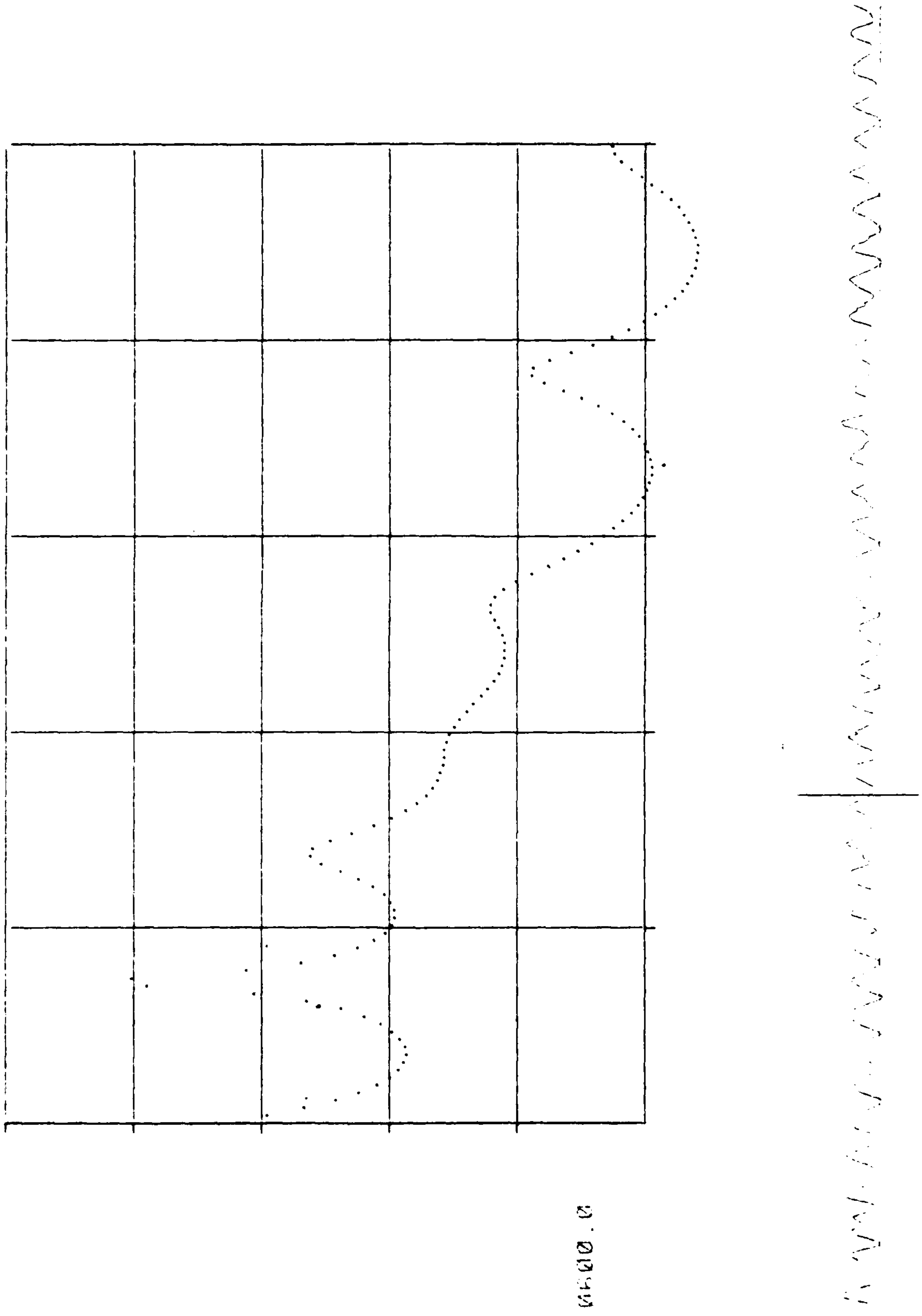
Coast Guard Morse Transcription - Preliminary Analysis
FEL Industries - January 1984



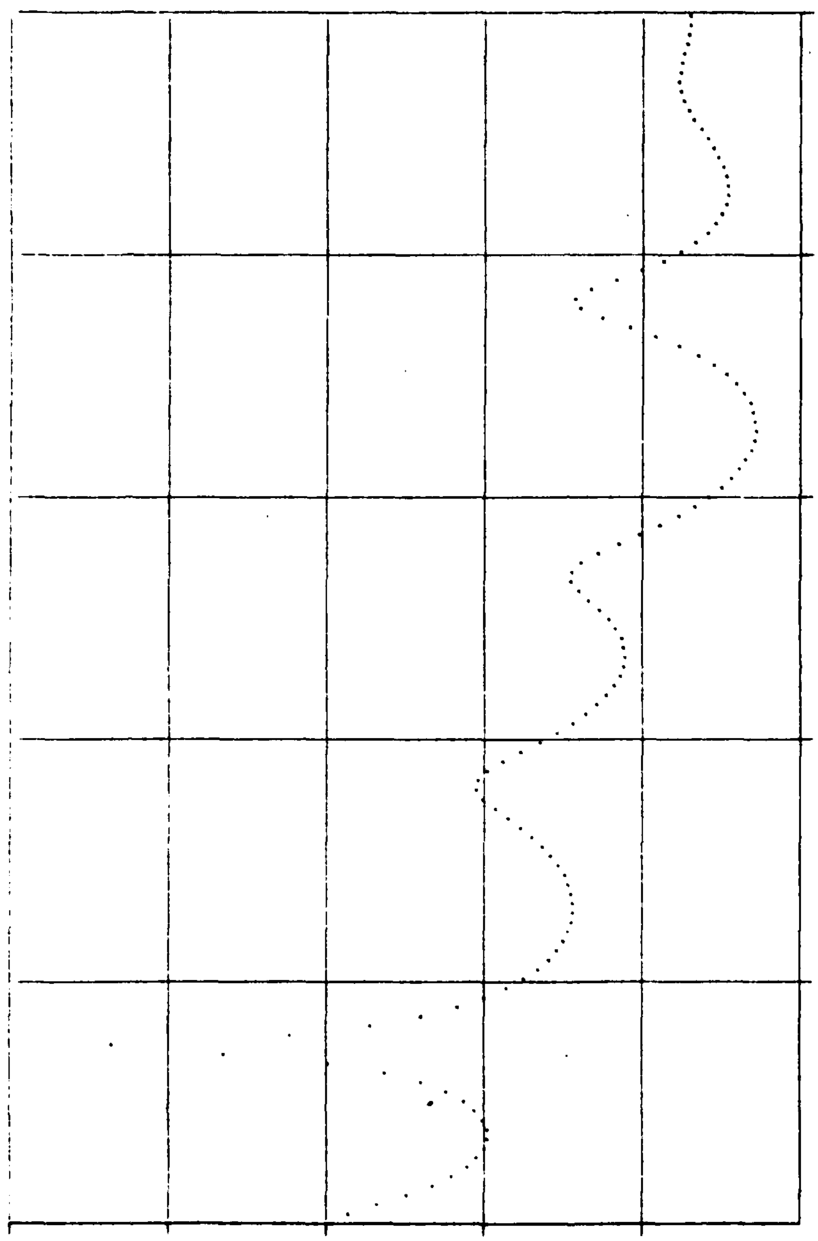
Coast Guard Morse Transcription - Preliminary Analysis
FEL Industries - January 1984



Coast Guard Morse Transcription - Preliminary Analysis
FEL Industries - January 1984



Coast Guard Morse Transcription - Preliminary Analysis
FEL Industries - January 1984



REFERENCES

(1) "Study of Automation of Message Handling Functions at USCG Comsta/Radsta and Communications Centers", Computer Sciences Corporation, May 1978, Report Number CG-D-18-78

(2) Smith-Vaniz and Barrett: "Morse-to-Teletype Code Converter", Electronics,; July 1, 1957.

(3) Gold, B.; "Machine Recognition of Hand-Sent Morse Code", IRE Transactions on Information Theory; March, 1959.

(4) Petit, R.; "Technical Manual: Morse to Teletype Code Translator" 1972, (Petit Logic Systems, P.O. Box 51, Oak Harbor, Wa. 98277).

(5) Bell, Edison Lee; "Optimal Bayesian Estimation of the State of a Probabilistically Mapped Memory - Conditional Markov Process with Application to Manual Morse Decoding"; September 1977; Naval Postgraduate School, Monterrey, California.

(6) Guditz, Ralph Howard; "Computer Transcription of Hand-Sent Morse Code Using Properties of Natural Language"; May 1975; Massachusetts Institute of Technology, Cambridge, Massachusetts.

(7) Makhoul, John I. "Spectral Linear Prediction: Properties and Applications", 1975, IEEE Transactions on Acoustics, Speech and Signal Processing, Vol ASSP-23, No. 3, pp 283-296.

END

DATE
FILMED

4 – 84

DTIC